

METAL PROGRESS

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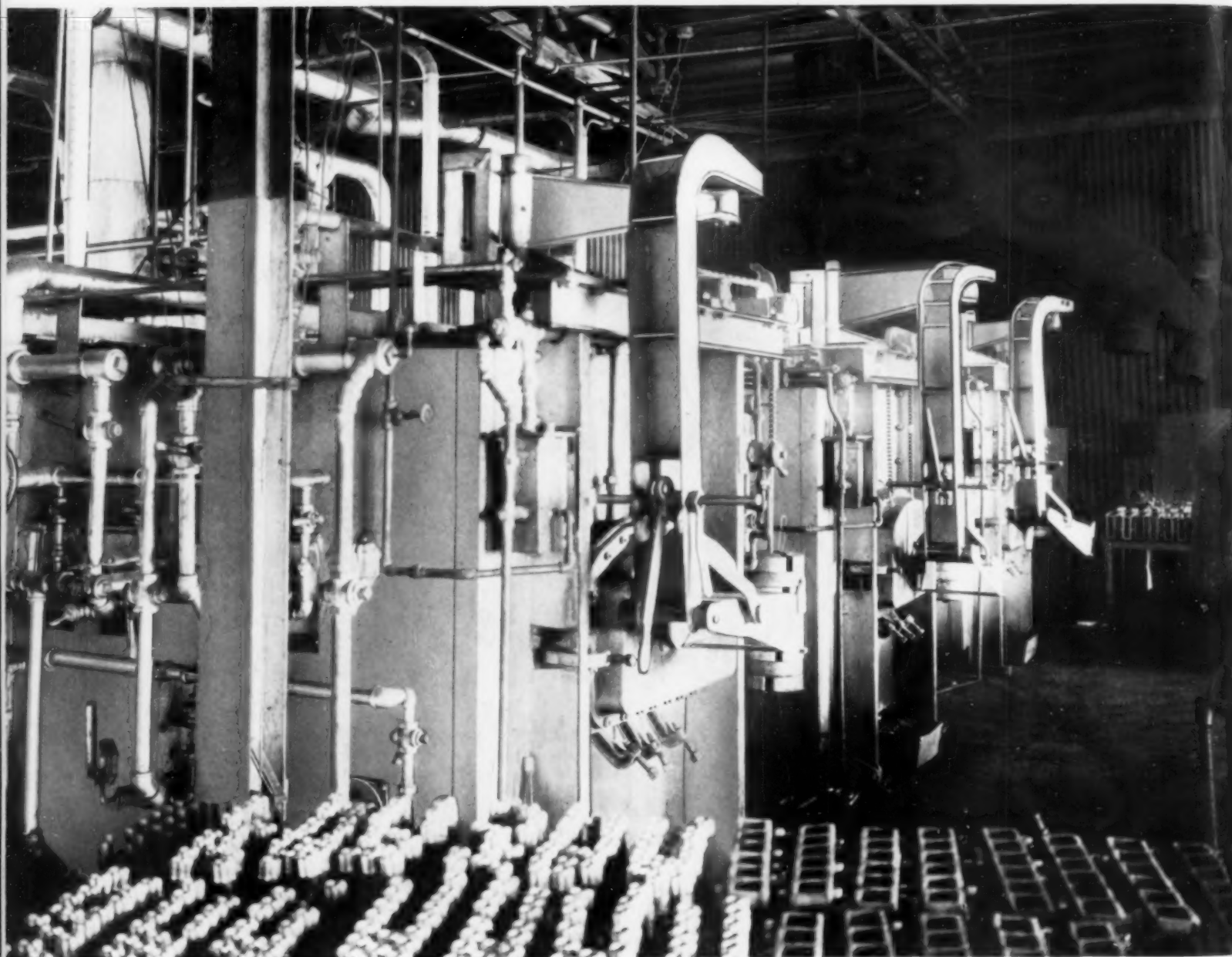
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Ernest E. Thum

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METAL PROGRESS

VOL. 33

JANUARY, 1938

NO. 1

PURE METALS

An Editorial

PERHAPS the search for "pure" metals is fundamentally due to our innate urge to strive for the unattainable, to hitch our wagons to a star. The experimentalist in metallurgical and physical laboratories wants the purest metal he can get, to make sure that the properties he observes are characteristic of the main substance, unaffected by minor contamination. The industrialist remembers that exceedingly pure metals sometimes have been great commercial successes. However each performs in its own way, and it does not follow that pure metal must have superlative properties.

But first, what are the "pure" metals that are now available, and how pure are they?

Of the commercial successes, 99.99% zinc for die casting alloys has been widely publicized. Oxygen-free copper has unusual ductility and toughness and is immune to embrittlement by hydrogen and other reducing gases. Hoopes' process aluminum, 99.98%, has notably improved corrosion resistance. Whether or not "pure" iron will be useful is still unknown, for we have never made any, even tediously refined in the laboratory to a degree that compares with the purity rather readily attained by several other common metals.

In pursuing, even briefly, the subject of pure metals, it may be worth while to revert at the outset to what we find in nature, and it quickly becomes evident that impurity rather than purity is the "natural state." Nearly all of our metals are completely oxidized or sulphidized and joined with other metallic oxides and sulphides in minerals, more or less complex and variable. Of the few that are found native, gold nuggets are not so pure, the California placer product being sometimes no better than 880 fine (88.0%). Natural irons or metallic meteorites are iron-nickel alloys. Lake copper is therefore quite unusual, having only about 0.1% impurities as measured by routine analysis.

Of these three (gold, iron, copper) iron is the hardest to refine to its utmost because chemically it is so reactive. Impurities in gold are slagged by fluxes which gold resists perfectly, and metal 999.75 fine (99.975% pure) is readily available to jewelers

—and even others before Uncle Sam decided he wanted all of it in his vaults. "Proof gold" used by assayers should be 99.998+ (impurities less than 20 parts per million).

The second common "pure" metal is electrolytic copper. Cathodes, melted and cast in open molds, can easily go 99.95%; most of the remainder is oxygen, left behind to control the casting and rolling properties and incidentally to prevent the entrance of other impurities. This oxygen, as well as other minor constituents, can be avoided by melting clean cathodes and casting them in a closed system under controlled atmospheres (or by adding precise quantities of various strong deoxidants) and such "oxygen-free" copper is so produced in considerable tonnage to 99.98% pure, a metal having definite advantages and uses.

Wrought iron made on the ancient hearth of purest ore and charcoal may have a metallic portion 99.85% pure, but contains from 0.6% slag to five times as much. As soon as you melt this to remove the slag, the same trouble begins that besets other commercial steel making processes. Low carbon bessemer steel has too much manganese (about 0.25%), a surplus remaining from the deoxidation stage. Ingot iron is doubtless our purest commercial iron; at least 0.20% impurities in it are mostly inherited from alloy in the steel scrap used as raw material. "Super-pure" electrolytic iron, melted in vacuum, costs \$2 per pound and is close to 99.97% iron, and at present is nothing much more than a base for precise experimentation.

The situation can be seen at a glance:

	PUREST COMMERCIAL	PUREST EXPERIMENTAL
Copper	99.98	?
Gold	99.975	99.998+
Iron	99.8	99.97

Very high degrees of purity are commercially achieved by metals whose boiling point is so low that they can readily be distilled and re-distilled from natural sources. One can guess that mercury would be the best example, and H. W. Gould writes that he has been unable to find a "trace" of any impurities in metal from the California mines. The case of mercury is interesting from another angle:

It has at least eight isotopes, and as much as 0.2% difference in density of metal from different sources has been reported and ascribed to their varying proportions. So whenever we reach the ideal state of purity we would still have to determine the isotopes and their properties!

Purity of distilled zinc depends on the purity of the ore; "prime Western" might contain 1½% of lead alone, whereas the total impurities of "high grade" zinc from New Jersey and Tennessee ores would be no more than 0.10%. Commercial brands (either made by electrolysis or reflux distillation) are now available 99.99% pure; while these brands may run 99.995, they will command only a moderate premium. "Chemically pure" zinc (99.998%) can be had at \$5 per lb., and "super-pure" (99.9999% or impurities 1 part per million) at \$20.

Soft lead can be highly refined because of the fluxing and cleansing action of its own oxide. Metal 99.94% pure for manufacture of pigment is called for in an old A.S.T.M. specification, and of course this is regularly exceeded. Electrolysis of lead bullion by the Betts process is now producing, on a tonnage scale, metal analyzing 99.998% (impurities 20 p.p.m.).

Commercial aluminum by the Hall process is not so very pure, being contaminated by impurities in the raw materials and carbon electrodes; its top limit is 99.8%, although "pure aluminum" is usually quoted as 99.0 to 99.5%. Electrolyzing a copper-aluminum alloy by the Hoopes process produced, commercially, 99.98% metal in 1925 and it is used extensively as the protective surfacing over the "alclad" strong alloys. Aluminum 99.99% or better is now available from the French Gadeau process, and has been offered at about 50¢ a lb.

* * *

Let us conclude the list with some data on other metals, collected by Thomas A. Wright for an A.S.T.M. committee interested in samples of standard purity for spectroscopy. The figures (subject to the known and unknown difficulties of analysis) are in percentage and parts impurities per million, and represent highest known and verified values, and are by no means commercial metals: Antimony 99.88% (1200 p.p.m.); bismuth "super-pure" 99.9984 (16 p.p.m.); cadmium "super-pure" well over 99.99 (100 p.p.m.); magnesium "super-pure" at least 99.97 (300 p.p.m.); tin "super-pure" 99.995 ± 0.002 (50 p.p.m.); silver 99.9999 (1 p.p.m.); platinum 99.998 (20 p.p.m.).

It is appropriate to define the meaning of the above figures. "Magnesium 99.97%" represents an arithmetical difference after suspected impurities are separated and determined, and the result not only depends on the skill of the analyst and the adequacy of his methods, but also on the extent of his search into the periodic sequence. In the more common metal, ingot iron, the Handbook gives

0.06% total impurities, meaning only the five common elements carbon, manganese, phosphorus, sulphur and silicon. It might be inferred, then, that ingot iron is 99.94 pure. However, "Standard Sample of Open Hearth Iron," issued by the National Bureau of Standards lists eleven other elements and the total impurities add to 0.222%.

Where do we stop? Obviously figures for purity mean nothing except ballyhoo unless the name of the impurity is given, its amount accurately determined, and its influence (good or bad) be understood, and unless it is sure that the best available analytical method shows no evidence of other contaminations known to be damaging for the purpose intended.

So much for the data on the present situation as to pure metal. A pertinent inquiry might be made as to the reason for pursuing the matter at length. Obviously the very highest purity is desirable for standards for spectroscopy and chemical analysis and for fundamental researches in metallurgy and physics. But is there any commercial significance to these scientific curiosities?

Some high purity metals have exhibited such interesting advantages — capable of being profitably exploited — that it is tempting to conclude that as metals approach the perfect state they take on a "noble" character, and that this is a general feature of super purity or even perfect purity. Such a conclusion is highly questionable. Take zinc. Why stop at 99.995% which made its mark in die castings? Scientists at New Jersey Zinc Co.'s laboratory have chased out nearly all of those remaining "traces" and find that the super-pure metal has elastic limit near zero — that is, will not support its own weight without steady creep. It is hard to imagine a use for such a metallic "pitch"!

Likewise in the case of iron. The purest iron has been made by men interested in magnetic and telephonic equipment, and it has been found to have certain superlative magnetic properties, but it is no secret that it is far easier to get the necessary characteristics for the most exacting present equipment much more cheaply by alloying commercial iron with commercial nickel. Ingot iron could also be made considerably purer, if there were any commercial reason therefor, by selection of raw material, since a third of the impurities consist of the circulating load of alloying elements in scrap.

Bearing in mind the strengthening effect of carbon, the grain refining effect of dispersed oxides, the toughening effect of nickel, and the corrosion resisting effect of copper and chromium, the present-day producer and user of iron and steel are actually more interested in a controlled amount of "impurities" than in super-pure metal. In fact, "controlled impurities" in pure metals will probably be the technical end of the scientist's efforts — as pointed out in the case of copper-lead alloys in Dr. Osborg's article in this issue.

Annealing time for malleable iron has been reduced to a fraction of former requirements by improved melting practice, adjustment of composition, but most especially by use of controlled atmosphere

furnaces (heated by radiant energy from appropriate elements). This eliminates the need of pots and packing materials to protect the castings from scaling. Substantially neutral atmospheres are read-

ily maintained, despite the fact that the iron being annealed evolves large volumes of carbonaceous gases during the heating cycle. Both continuous and batch type furnaces are now in successful operation.

FASTER ANNEALING OF MALLEABLE CAST IRON

B Y J. T. B R Y C E A N D H. G. S C H W A B
metallurgist development engineer

S U R F A C E C O M B U S T I O N C O R P., T O L E D O, O H I O

ACROSS the continent by rail in six days! Not so long ago that was a sensational achievement. Today we smile at its recollection but turn grimly to the serious task of malleableizing white cast iron in the same length of time. As a matter of fact, it is no more necessary today to anneal white iron on a six-day time cycle than it is to use up six days in crossing the country. While transportation has been quickened remarkably in the past century, the malleable iron industry, as important as it is to our industrial life, has lain practically dormant. Fortunately it now also is on the threshold of a modern era, one which is not only desirable, but inevitable.

Seth Boyden introduced a new industry to this country when in Newark, N. J., in 1826 he first made "black-heart malleable iron." For a century others followed the rule-of-thumb methods of its inventor. True, there have been improvements in the physical properties of the product due to better control of the technique and raw materials, but fundamentally Seth Boyden's methods are still dominant.

They comprise, as is well known, the melting of a high silicon, low carbon cast iron in an air furnace of the reverberatory type, and the resulting castings (hard, white iron) are

cleaned, packed in a protective box, and heated a long time to convert all the combined carbon into particles of free graphite.

Now, how can this process be modernized? In the first place, the melting practice may be modified. In 1935 75% of the total tonnage of malleable iron was melted in the air furnace, 8% in the cupola, and 15% was duplexed (either cupola melted and electrically refined, or cupola and air furnace). But these figures do not present a comprehensive picture of the situation from a standpoint of number of foundries. That is, while 15% of the total tonnage was duplexed, less than 4% of the foundries used this process. Naturally this group represents the largest individual companies and those more able financially and technically to adopt this improvement.

Duplexing offers three distinct advantages: First, closer chemical control of the iron is possible; day-to-day analyses and pouring practice show better uniformity. Second, it permits superheating, the practical value of which should not be underestimated. By this technique the over-all annealing time may be greatly reduced, as shown in the first curve, an effect generally held to result from the formation of a greater number of graphite nuclei. Third,

it lends itself most conveniently to continuous pouring. Naturally this advantage is confined to the large production shop.

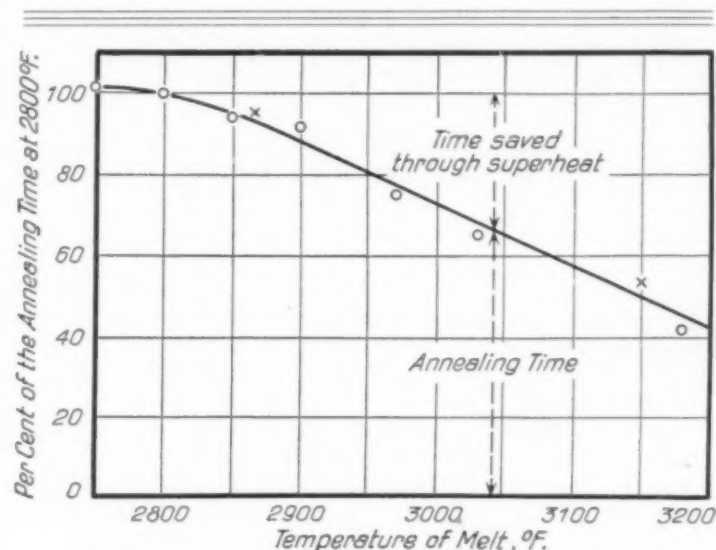
In recent years there has been a tendency to rearrange the carbon and silicon contents of the commercial melt. Study of the carbon content has indicated that high carbon, up to a certain point, increases the time required to graphitize the excess cementite, but tends to decrease the time required to graphitize the carbide precipitated from the austenite on cooling. Low carbon increases physical properties (as shown by the table of values below taken from American Foundrymen's Association *Cast Metals Handbook*); it also increases the required pouring temperature. (In this connection research on sand control may develop a molding technique capable of successfully handling higher pouring temperatures.) However, the carbon content is very closely associated with the silicon content. Silicon is universally recognized as the primary element which induces the graphitization of the carbon. Higher silicon reduces the carbon dissolved in austenite and raises the critical point, and since "second stage annealing" (that is, the decomposition of carbide that has been in solid solution in austenite during the first stage) is done just under the critical, higher temperatures for this stage may be used with resulting speed-up. Silicon also increases the formation of graphite nuclei.

The desirable objective in readjusting the carbon-silicon ratio is therefore a product having good castability, free from primary graphite, and readily annealed in the shortest time. These same results may also be attained by alloying other metals which reduce the solubility of car-

bon in austenite; nickel, copper, aluminum and several other elements have been recommended for this purpose.

IMPROVED ANNEALING METHODS

Thus far we have touched lightly on several of the factors which may effect the inevitable



Superheating of the Molten White Iron Speeds up the Subsequent Malleabilizing Anneal, Possibly by Formation of Large Number of Graphite Nuclei (Data by R. Schneidewind and A. E. White)

modernization. It is our purpose now to discuss in greater detail the developments in annealing methods being introduced today. Continued use of malleable castings, particularly in the automotive and tractor industries, has necessitated a speed-up in the production. "Malleable" is a very desirable engineering material, but has lost many competitive uses because of the time required to produce the finished part

Properties of American Malleable Iron

	1937 Cupola Melted (or 1920 Air Furnace)	A.S.T.M. Specification A 47-1933	
		Grade 32510	Grade 35018
Range of composition, white iron			
Carbon	2.80 to 3.10	2.25 to 2.70	1.75 to 2.30
Silicon	0.70 to 1.10	0.80 to 1.10	0.85 to 1.20
Maximum temper carbon in malleable	—	2.20	1.80
Mechanical properties (probable values)			
Ultimate tensile strength, psi.	45,000	50,000	57,000
Yield point, psi.	35,000	32,500	37,500
Elongation in 2 in., %	8	14	22
Izod impact, ft.-lb.	8	12	16
Brinell hardness	110	110 to 145	110 to 145

after the order is placed. Modern production schedules frequently will not permit a lag of two to three weeks, and as a result, forgings and stampings have supplemented malleable castings, not because of inherent superiority but because of prompt availability.

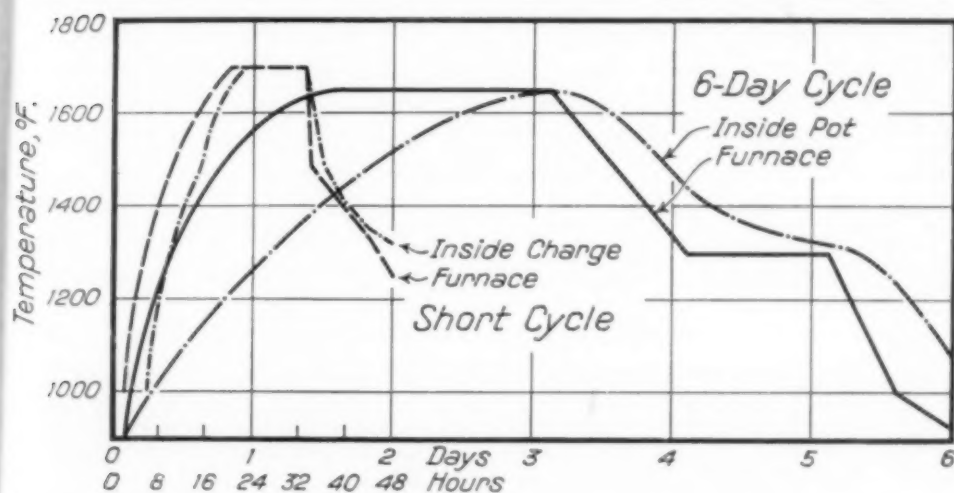
Let us consider the annealing practice as it has been followed in the past. The white iron castings were placed in large annealing pots, and a suitable mixture of sand, scale and charcoal packed around. This procedure was followed to exclude much of the air and thus protect the castings from excessive scaling and decarburization; it also offered much support to the castings during the long heating and thus reduced warpage. It will be readily noted

ago (about 1500° F.) but to be sure to avoid under-annealing the time was not shortened much, and the minimum fuel costs in the old type of furnace were reached at temperatures somewhere between these extremes.

One of our colleagues, C. B. Phillips, writing in METAL PROGRESS in 1931, records that the best annealing time then commercially achieved was four days at the Southern Malleable Iron Co. in East St. Louis. This was by means of a three-day heating at 1650° F. to decompose excess carbide, and a slow cooling, step by step, to graphitize the cementite precipitated from the austenite.

In more recent years this cycle has been reduced to somewhere between 60 and 80 hr.

by the use of car-bottom continuous type kilns for handling castings packed in pots. Their use has been limited principally to the large foundries because of the initial investment and the necessity of a high production schedule. Another development was the introduction of the brick muffle type oven fired by either gas, oil or powdered coal. This oven eliminated the need for pots and packing material, but because of its low heating efficiency and the fact that it did not materially decrease the heating cycle, was never popularly accepted.



Old Time-Temperature Program for Annealing Automotive Castings in Pots Against Today's Practice in Controlled Atmosphere. Note short time lag between temperature of work and modern furnace

that the net mass of the castings will average only about 40 to 50% of the gross charge in the annealing oven. Good annealing practice called for a heating cycle of from five to seven days. This total time may roughly be subdivided as follows:

1. Heating from cold to 1650° F. or thereabouts in 40 hr.
2. Holding at 1650° F. for 45 hr.
3. Cooling through critical temperature and holding just below, 40 hr.
4. Cooling enough to handle castings, 5 hr.

This totals 130 hr. or 5½ days. The minimum cycle on such a schedule is approximately seven days, as quite some time is required for charging and unloading. These temperatures are higher than the standard practice of 15 years

The great need of the industry was for a furnace which would combine the advantages of high heating efficiency with cheap fuel, fast cycle, elimination of pots and packing material, and protection of the surface of the work. All these requirements have now been satisfactorily fulfilled by the controlled atmosphere furnace using gas-fired radiant tubes as heating elements.

Now why controlled atmosphere, and why gas-fired radiant tubes? First of all, a controlled furnace atmosphere removes the necessity of protection by heavy pots and packing material. This results in increased thermal efficiency as this additional load does not have to be heated. Furthermore, handling costs per ton of annealed iron are lowered and the

handling time reduced. While the initial cost of the alloy trays on which the work is conveyed through the furnace may be equal to the capital investment in pots for an equal sized oven, the unit charges for replacement are much lower. Scaling of the work is entirely eliminated and decarburization appreciably reduced. The annealing cycle is considerably decreased because the work can be heated and cooled much more rapidly and uniformly. This permits the time at the various stages of the anneal to be cut to a minimum.

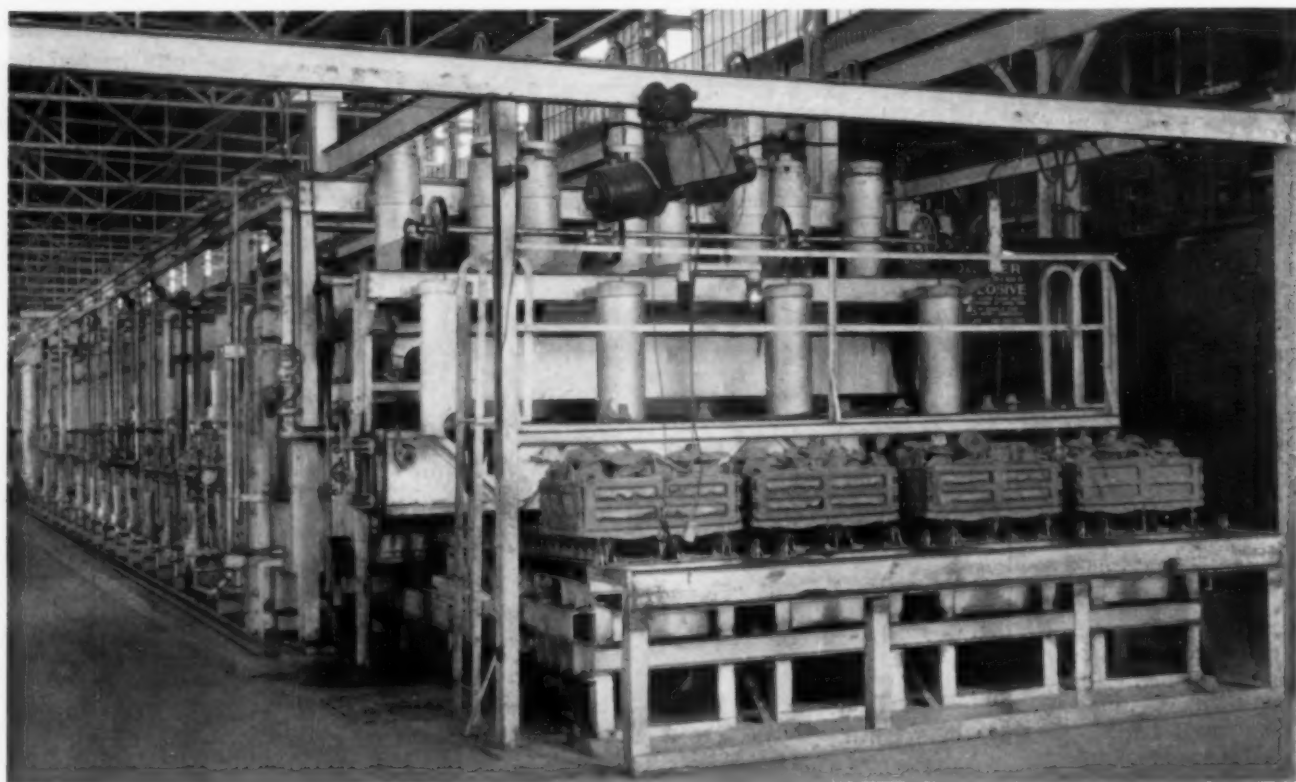
— A graph on the preceding page compares the heating cycle of the old style oven with that of the controlled atmosphere furnace. Notice the variation between furnace temperature and work temperature, and the difference in lag between the two cycles. Another advantage, which is quite difficult to evaluate in terms of dollars (but not sense!), is the cleanliness of this type of furnace.

The gas-fired radiant tube provides a means of heating a chamber without the necessity of a separate muffle to protect the work from the flue gases. Combustion in this type of heating element is controlled to provide even temperature of the tube from end to end, thus

insuring uniform heating of the work. The Surface Combustion Corp.'s radiant tube was described in METAL PROGRESS by Messrs. Hepburn and Weller in August 1935, and the fundamental principles of diffusion combustion discussed by W. M. Hepburn in the September 1932 issue. This tube operates at all times under negative pressure, which makes it impossible for the products of combustion to escape into the furnace. Hence one can postpone repairs until it is convenient, or until the production schedule permits.

So far this method of heating has shown only a lower cost advantage over electric radiant heating. However, it has the decided additional advantage of being able to cool the work uniformly by the simple expedient of turning off the gas and allowing the negative pressure to induce a cooling draft of air through the tubes.

The atmosphere is prepared in a unit separate from the furnace, and we term it "DX gas." Either natural or manufactured gas is suitable for raw material and is automatically proportioned with correct amount of air to produce a gas of desired analysis. This reaction between the air and gas is exothermic, and is



Charging End of Continuous Annealer Where Trays of Castings Are Locked Into Long Hearth, and Heated in Controlled Atmosphere Through Correct Temperature Cycle Enroute to Discharge End

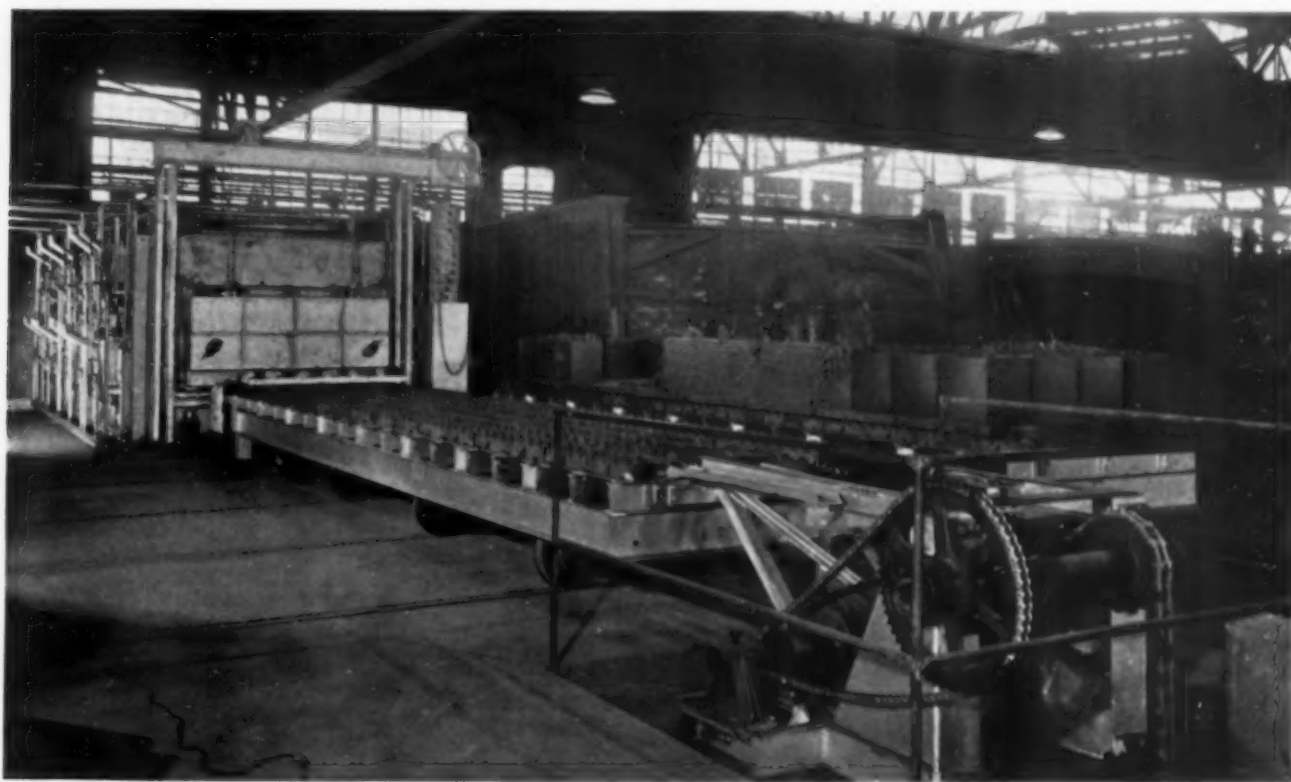
carried on in a refractory lined chamber at a relatively high temperature. The products of this combustion are then passed through a small cooling tower where they are "scrubbed" and the dew point lowered to approximately the temperature of the cooling water. The resulting gas is oxygen-free, of uniform composition, relatively dry, and clean.

GASES GIVEN OFF BY WHITE IRON

Theoretically the furnace atmosphere should be in equilibrium with the work under all temperature conditions. The problem of atmosphere in the malleable furnace is complicated by two conditions not ordinarily found in dealing with controlled atmospheres. First, the wide range of temperatures and the length of time at the various temperatures require a gas of varying carbon potential. (By carbon potential is meant the complex relationship between the carbon oxides, hydrogen, hydrocarbons and moisture required to effect a desired surface reaction—or absence of reaction, as the case may be.) Second, the white iron itself gives off a carbonaceous gas during the heating range between 1550 and 1750° F., and this enriches

the supplied atmosphere. It follows, then, that as the iron loses carbon, a lower carbon potential gas is required to maintain equilibrium at those temperatures. However, to complicate the problem further, the gas itself "re-forms" on raising the temperature, some chemical reactions taking place between the various components of the hot furnace atmosphere, thus shifting the equilibrium point of the gas, so that the resulting carbon potential is increased. It is extremely important during the high temperature anneal not to increase the carbon potential to a point where the work is carburized on the surface, as this condition resists graphitization at the lower temperature range.

In spite of these handicaps, controlled atmosphere has successfully been applied to two types of furnace, the continuous and the batch. The continuous furnace is essentially a long heating chamber equipped with charge and discharge vestibules. The work is stacked on alloy trays of suitable size and pushed progressively through the furnace; each tray may have its own set of rollers. In operation the loaded trays are placed on the loading platform and are pushed into the charge vestibule, which is then closed and purged of air. At

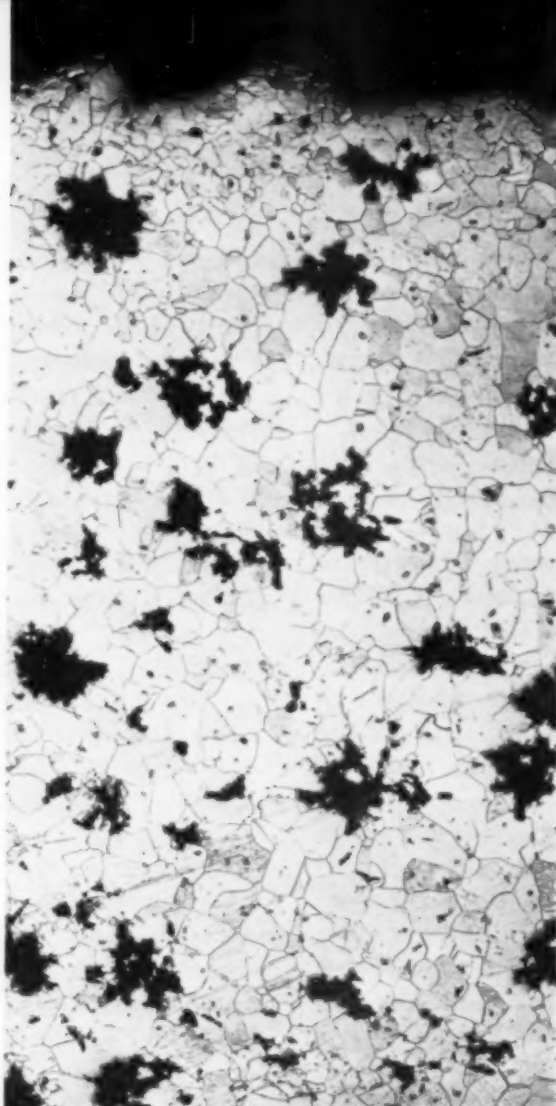


Batch Type Annealers—Old Style in Background for Box-Packed Castings; New Style at Left for Heating Bare Iron in Controlled Atmosphere. Radiant tubes (gas fired) are the heating mediums

the correct time the inner charge door and discharge door are raised, and the trays pushed into the furnace. Simultaneously, a corresponding set of trays loaded with annealed castings is pushed into the discharge vestibule at the far end of the furnace. The inner doors are then closed, the outer discharge door opened, the bank of trays removed, the door closed and air purged from the discharge vestibule. This cycle completes the entire mechanical operation of the furnace and is repeated at definite time intervals.

The burner arrangement is so designed as to conform to the desired heat cycle, all zones of the furnace being automatically controlled. Rapid cooling from the high temperature to the second stage annealing temperature (1100° F.) is done in a zone taking 90 min. for the work to traverse by drawing cooling air through a series of alloy tubes placed above and below the work.

The atmosphere problem encountered in such a continuous furnace is handled by introducing a lean DX gas at the charge end and bleeding the effluent atmosphere gas through the discharge vestibule. The gas on entrance has an analysis of about 11% carbon dioxide, 1% carbon monoxide, 0.0% oxygen, 1% hydrogen, and 0.3% methane. In the high temperature zone of the furnace the atmosphere is re-formed by the evolution of carbon (and hydrogen) from the charge. This amounts to about 6 to 8 lb. of carbon per ton of hard iron. At 1750° F. this addition enriches the atmosphere to approximately the following analysis: 6.0% carbon dioxide, 13.5% carbon monoxide, 0.0% oxygen, 3.0% hydrogen, 0.6% methane. If a steady through-put of castings is maintained, carbon is evolved at a constant rate, which with the



Microstructure of Normal Malleable Produced on a 46-Hr. Cycle in Controlled Atmosphere. 100 ×

input of DX gas, creates a uniform atmosphere from the high temperature zone to the discharge vestibule.

Let us now consider the batch type of annealing furnace. This is essentially the high temperature zone of the continuous furnace fitted with a door at either or both ends. Depending upon the available floor space the furnace may have a loading table at each end, or two transfer cars at one end. With the single door design, the work to be annealed is loaded on alloy trays approximately 24 by 36 in., fastened together to form a continuous flat surface approaching the inside dimensions of the furnace. These trays rest upon one of the transfer cars in front of the furnace.

The door is opened, the charging mechanism attached, and the load drawn into the furnace. The door is closed and the heating cycle started. When the annealing cycle has been completed, the door is opened and the load withdrawn onto the waiting transfer car. This car is shunted to one side and the second car, which has been loaded with hard iron, is moved into charging position and its load pulled into the hot furnace.

The two-door or double-end design has the advantage of materially cutting the charging time. By this scheme two tray sections are placed end to end; one section, loaded with castings, is within the furnace while the other is outside of the furnace on one of the loading tables. At the end of the annealing cycle, the doors at each end are opened and the two tray sections hooked together. The charging mechanism is then attached and the loads moved in tandem, the annealed casting leaving the furnace by one door as the fresh charge enters by the other. The direction of pull necessarily reverses with the succeeding heat.

The application of controlled atmospheres to the batch type furnace meets quite a different situation from that encountered in the continuous type. Evolution of carbon from the charge takes place only on heating from about 1550° F. to 1750° F. This means that after the carbon has been given up by the metal, the carbon potential of the atmosphere must be directly controlled. Such control requires the use of a richer DX gas having an approximate analysis of 5% carbon dioxide, 9% carbon monoxide, 10% hydrogen, and 2% methane.

This method has the advantage of greater flexibility in that the carbon potential of the atmosphere may be raised any time during the annealing cycle to conform to the requirements of the iron. Gas of the above analysis is in reasonable equilibrium with the iron up to about 1500° F. Above this temperature the rate of carbon evolution from the iron is not sufficiently rapid to maintain the equilibrium, ever changing with temperature. Therefore, it is frequently necessary to enrich the atmosphere further by raw hydrocarbon gas during preheating from 1500 to 1750° F. This must be done with caution as excessive amounts of hydrocarbon may increase the carbon potential to a carburizing condition. This materially increases the time required for second stage graphitization. It, however, is possible to maintain an atmosphere which is in equilibrium with the work at all stages of the anneal by the careful manipulation of the three elements — original DX gas composition, carbon evolution from the iron, and raw hydrocarbon addition.

CONTINUOUS VERSUS BATCH FURNACES

In comparing the two furnaces, it becomes evident that the continuous type is better adapted to the requirements of steady production. On the other hand, the batch type lends itself more handily to intermittent production schedules and a wider variety of iron compositions. The original cost is approximately equal on a tonnage basis. The continuous furnace, however, has an appreciably lower gas consumption, due primarily to the difference in design — that is, the continuous furnace remains at operating temperature throughout its entire length, and it is only necessary to supply heat for the incoming work and trays and for the normal radiation losses. With the batch type it is not only necessary to meet these requirements, but also to supply heat to raise the

temperature of the furnace itself from discharge temperature to soaking temperature.

Somewhat in the way of compensation, however, is the greater flexibility of the batch type furnace. (It must be borne in mind that this paper deals with normal malleable iron and not pearlitic, or other short cycle irons, although the furnaces described are perfectly capable of handling any of the special irons.)

The quality of the iron annealed in either type of furnace is the same and compares favorably with any annealed by older methods. The shorter heating cycle coupled with atmosphere control combine to decrease decarburization materially. Under certain conditions this improves machinability. However, the fact that the new type of annealing furnace so definitely reduces annealing costs per ton is the big reason why it is being accepted in the modern foundry. In addition it offers the malleable foundryman a means of reducing the delivery time, and an opportunity to recapture the business lost to the forging and stamping trade. It is the opening wedge in the foundry modernization which is sure to follow.

WELDED SHIP

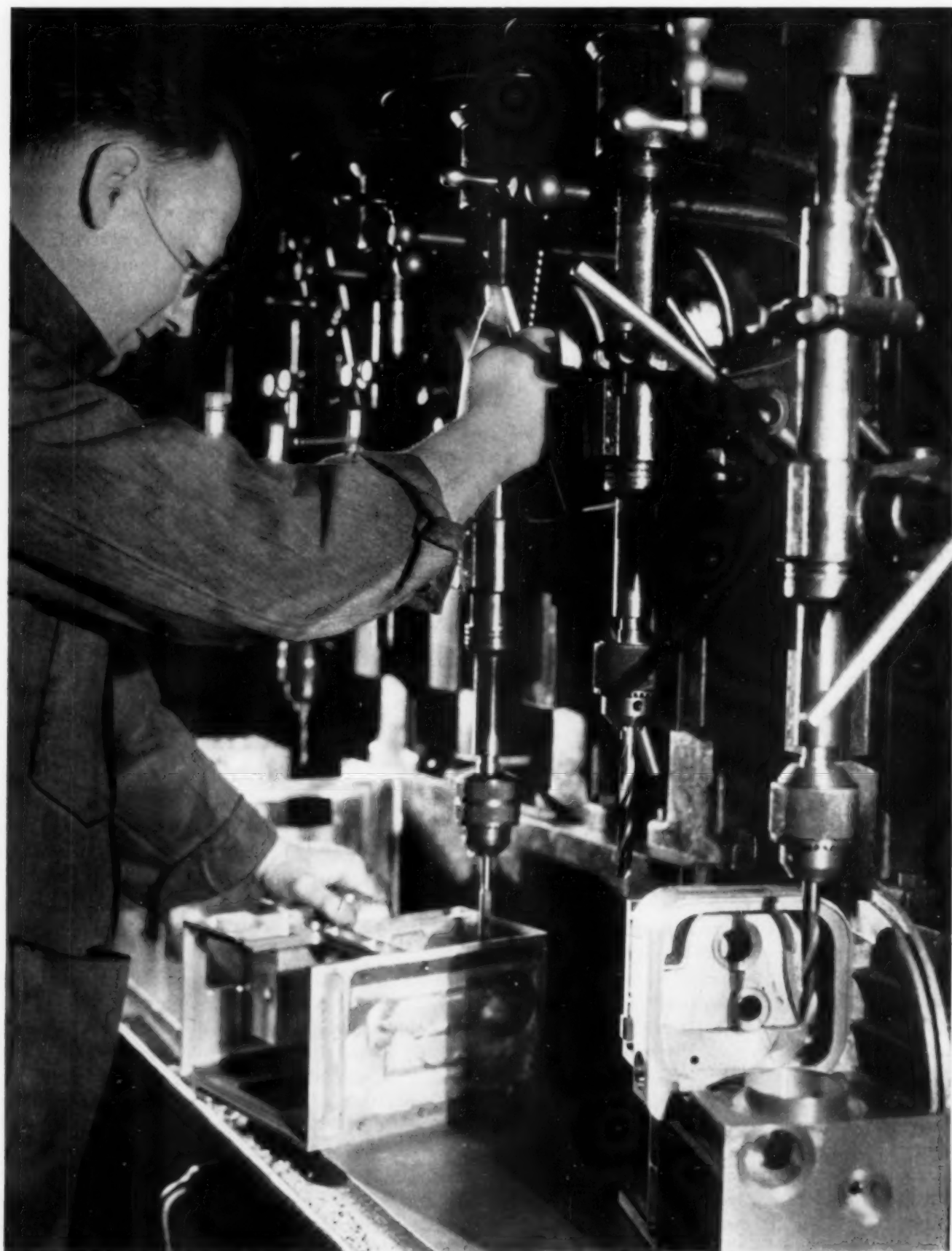
SURVIVES A MINE

BY H. STANLEY

Abstract of a paper before the Institution of Engineers and Shipbuilders in Scotland, October 19, 1937

A MODERN British destroyer, H.M.S. Hunter, struck a mine off the Spanish coast last May which demolished all the internal structure up to the upper deck throughout one seventh of the length (including one boiler room and two oil fuel tanks) and flooded one quarter of the ship. Thanks to proper subdivisions in the hull, however, the ship was safely taken to port. Outside of the demolished region, there was practically no other machinery damage.

The hull is constructed practically throughout of D-quality steel, a special steel extensively used in Admiralty warship construction, having an ultimate tensile strength of from 80,000 to 100,000 psi. and a minimum elongation of 17% in 8 in. In general, all the important structural work was riveted. The rivets used in the D-steel plating were of Admiralty DR-quality. This is somewhat similar in (Continued on page 84)



Machines and Machinery — All Must Have Reliable and Economical Bearings
Photo by Irving Browning, New York

Copper-lead bearings—long the favorite for railroad and massive machinery—are now being given a play in smaller bearings where pressures, speeds and temperatures run up. Unfortunately the lead

tends to segregate during casting, and multitudinous are the expedients used or patented to prepare metal with a uniform microstructure. Dr. Osborg here presents a systematic survey of these schemes, most

of which have to do with the addition of one or more elements or substances in minor amounts, and he indicates the desirable effects that are to be achieved and maintained and the pitfalls to be avoided.

MINOR CONSTITUENTS

IN COPPER-LEAD ALLOYS

BY HANS OSBORG, METALLURGICAL CONSULTANT, NEW YORK

COPPER-LEAD ALLOYS are most important bearing materials, and discussion in METAL PROGRESS since last August has reviewed their metallurgical, engineering and manufacturing aspects. However, the role of minor constituents has hardly been mentioned, and it is now the intention to present a simplification of the legion of polynary alloys in use or suggested in the literature.

The binary equilibrium diagram is presented on the next page, and shows that molten alloys containing 38 to 92½% lead are emulsions (unless highly superheated). To avoid the natural tendency of such alloys toward segregation, two methods are utilized: First, temperature control and suitable stirring, casting and chilling (which may be sufficient for compositions not too close to the border-line), and second, addition of minor constituents to contract the region where emulsions are formed.

Really it should be said that in or near the region of molten emulsions both expedients should be intelligently combined, for the fine and uniform dispersion of the lead and copper matrices in each other depends on the particle size existing in the liquid at the time of solidification of the copper matrix skeleton. (The lead matrix is the lead-copper eutectic and holds about 0.06% copper in solid solution;

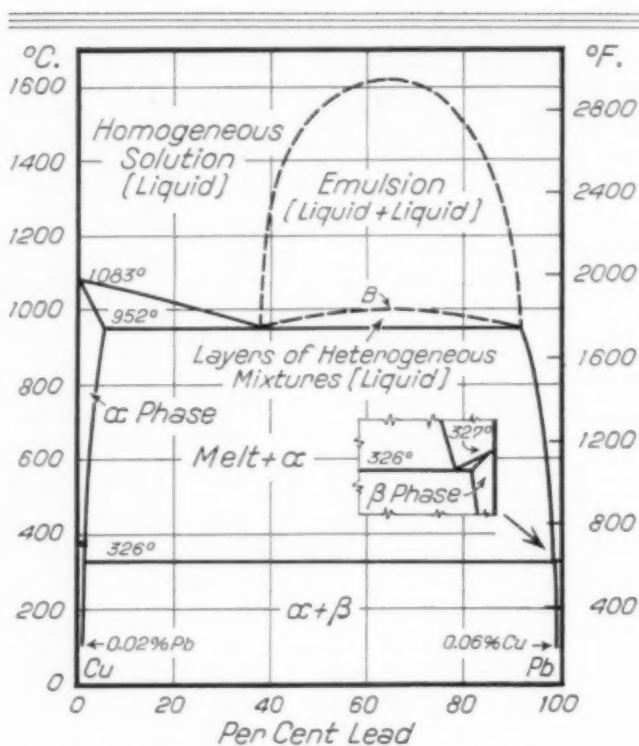
the copper matrix contains less than 0.02% lead.) Claus has frequently pointed out that these emulsions are governed by Stokes' law of settling, wherein the velocity of fall varies as the square of the radius of the particle or droplet and inversely as the viscosity of the fluid. Hence the difference in specific gravity of the phases is not of primary import.

Minor constituents may cause appreciable changes if present in amounts from spectroscopic traces to several per cent, and for our present discussion may include metals, non-metals, compounds and gases. It may also apply to semi-metallic constituents. A great many such additions have been made or proposed; the claims made for some of them often confuse the issue. It should be borne in mind that not all of them produce beneficial results (as far as bearing characteristics are concerned, at least); indeed, in some cases beneficial effects and detrimental characteristics result simultaneously.

I. *Solid Solution Bronzes*—In this first case, minor constituents are primarily added to strengthen the copper matrix; practically all solid solution bronzes high in lead belong to this group. Improvement in the copper matrix is, however, brought about at the expense of homogeneity.

A typical example of this is tin. Tin and copper form an intermetallic compound (CuSn_3) which is relatively stable in the melted (not superheated) alloy, and it apparently broadens the miscibility gap (the loop in the copper-lead alloys where emulsions occur). Tin bronzes consequently show a more pronounced tendency to segregate than straight copper-lead alloys having the same lead content. In order to overcome this tendency, they have to be overheated, as indicated in Briesemeister's ternary diagram shown on the opposite page — that is, the CuSn_3 has to be thermally dissociated. This overheating is undesirable, in view of the lower liquidus of the tin-containing copper-lead alloys.

An interesting element that probably belongs in this group is manganese. While no information has been published regarding the effect of manganese on the miscibility gap, the available evidence indicates that small additions promote homogeneity and dispersion in copper-lead alloys up to 40% lead, while more than 7% of manganese tends to cause segregation like tin. At 10% manganese, segregation is quite pronounced. Considering that the atomic weight of tin is about twice that of manganese, the difference in the influence of these two minor constituents becomes quite obvious. The much milder effect of manganese on segregation appears to be in agreement with the theory mentioned above in connection with tin: Copper and manganese form an uninterrupted series of solid solutions, and intermetallic compounds do not occur; consequently, overheating is unnecessary. In view of a slight tendency of such alloys toward segregation, the addition of 2% nickel was found advisable and alloys of the following compositions have been reported by Wecker and Nipper as quite satisfactory: 30% Pb, 5 to 7% Mn, 2%



Copper-Lead Equilibrium Diagram According to Willi Claus, *Zeitschrift für Metallkunde*, 1931, p. 265

Ni, and balance Cu.

II. Liquid Solutions Which Contract the Miscibility Gap —

In this case, the practical effect of the minor constituent is to broaden the area in which molten copper-lead alloys form true solutions; the miscibility gap can be closed entirely if a sufficient percentage is added. As the tendency of true solutions to segregate upon cooling is much less pronounced than that of molten copper-lead emulsions, addition agents of this type promote homogeneity.

Nickel is a representative; 1% is often sufficient to prevent segregation. The amount of nickel needed to close the miscibility gap of high-lead copper-lead alloys does not exceed 3%. Therefore the nickel addition, combined with controlled overheating, produces homogeneous alloys in practically all proportions.

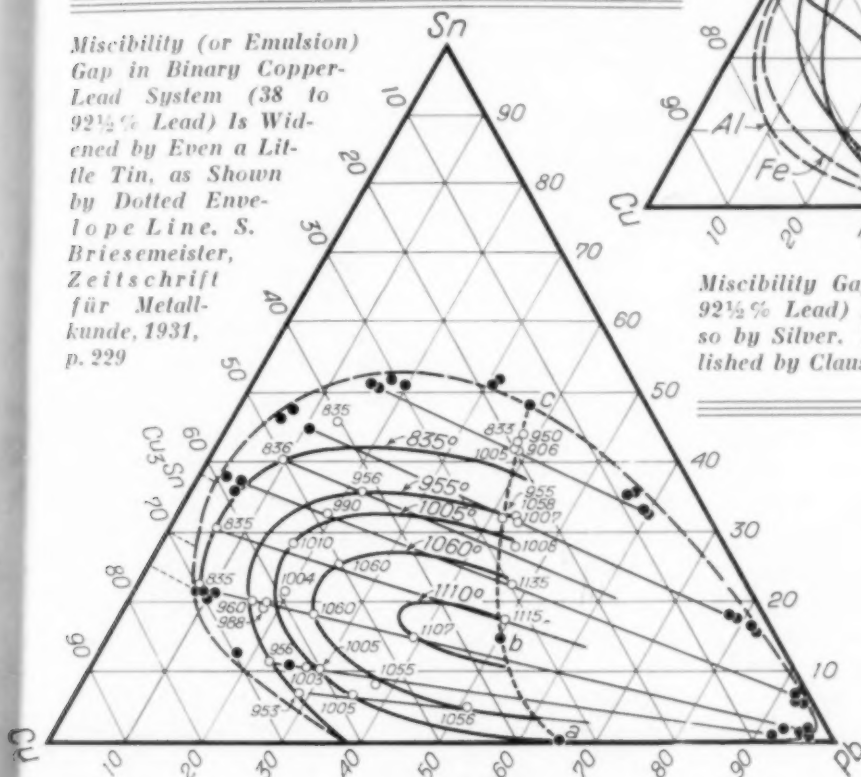
According to Guertler's diagram at right, p. 45, silver has a similar effect to nickel. The percentage needed to overcome the tendency of the two molten matrices to form emulsions and to separate into two layers is, however, comparatively higher.

III. Semi-Metallic Compounds, Soluble in the Melt, Insoluble in Solid — A third group of elements has an indirect influence. Sulphur is representative of this group. It forms semi-metallic compounds (sulphides) with copper and lead which have an appreciable solubility in the molten alloys, and it is the presence of these semi-metallic compounds that apparently changes the solubility relations of the base metals, each to each. The tendency of copper-lead alloys to segregate can be suppressed or eliminated thereby. Even upon slow cooling, single layer alloys can be produced by adding from 0.67 to 1.60% of sulphur, according to Guertler and Landau, *Metall und Erz*, 1934, p. 169, 269. After solidification, however, the solubility of the sulphides is considerably reduced

(a fact deduced from the circumstance that sulphur depresses the conductivity of copper only moderately) and they are precipitated from solid solution. Appreciable amounts of such hard and brittle precipitates in the microstructure impair the bearing qualities.

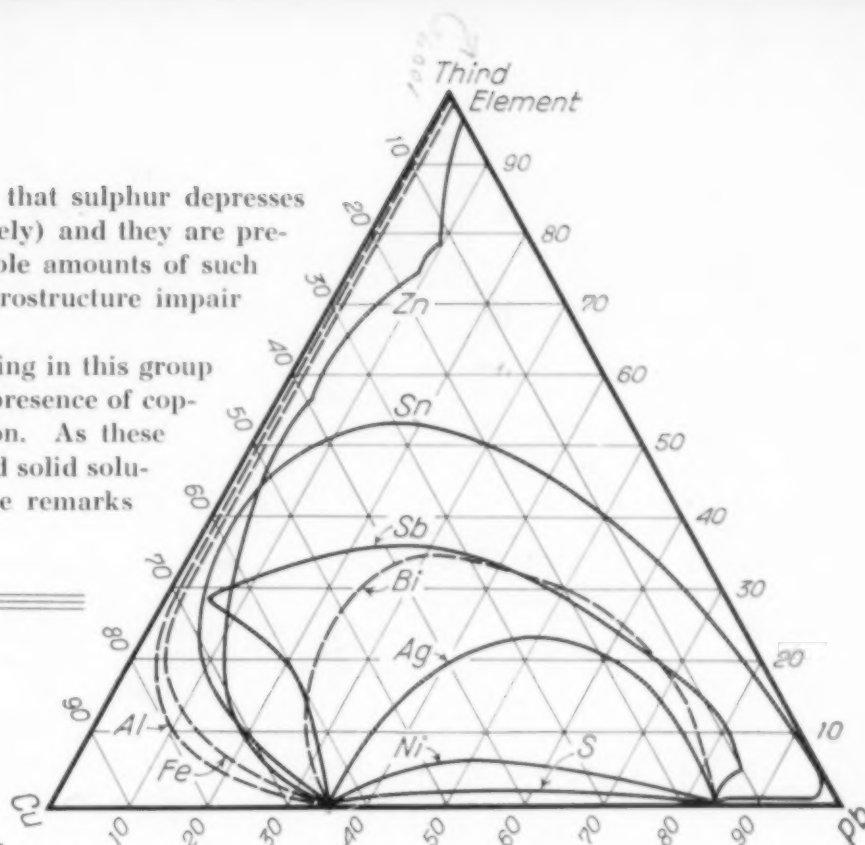
Another element quite likely belonging in this group is oxygen. It has been claimed that the presence of copper and lead oxides prevents segregation. As these oxides have, like sulphides, a very limited solid solubility in alloys of this nature, the above remarks probably apply.

Miscibility (or Emulsion) Gap in Binary Copper-Lead System (38 to 92½% Lead) Is Widened by Even a Little Tin, as Shown by Dotted Envelope Line. S. Briesemeister, *Zeitschrift für Metallkunde*, 1931, p. 229



IV. *Elements Effective in Minute Amounts*—A fourth group includes silicon, lithium, calcium and tellurium, which cannot be classified in any of the foregoing. These agents have no known influence on the constitutional diagram, and their solubility, particularly their solid solubility in copper and/or lead, is limited to fractions of 1%. Elements of this type have, however, a very noticeable effect on strength, grain size, and hardness of one or both of the matrices of copper-lead alloys. If present in amounts not or only slightly exceeding their solid solubility, they improve certain physical properties of one or both of the matrices, but do not modify characteristics of the alloy to such an extent as do the solid solution bronzes.

In the event that elements of this type are



Miscibility Gap in Binary Copper-Lead System (38 to 92½% Lead) Is Contracted Notably by Nickel and Less so by Silver. This diagram ascribed to Guertler is published by Claus in *Zeitschrift für Metallkunde*, 1936, p. 86

present in amounts noticeably exceeding their solid solubility in either one of the matrices, they can be expected to produce undesirable effects, especially brittleness, due to the occurrence of insoluble intermetallic compounds.

On the other hand, they must be present in amounts of more than about 0.001% in order to be effective at all. The useful range is thus restricted to residual per-

centages varying from approximately one, or several, thousandths to about one or several tenths of one per cent.

V. *Purifying Agents*—A fifth group of elements used or suggested as addition agents comprises those which function as scavengers. They deoxidize, degasify and desulphurize the molten alloy, thus producing cleaner metal and more uniform and higher average physical properties. If most of these refining agents are added in amounts exceeding those needed for purifying purposes, they fall into the fourth group mentioned just above.

VI. *Presence of a Second Minor Constituent*—In the foregoing, the presence of only one minor constituent has been considered. In practice the situation is not always as simple;

furthermore, there are transitions from one group to the other. Quite different conditions may prevail if a second minor constituent is present. Thus, the addition of about 0.05% of phosphorus to tin-containing copper-lead alloys noticeably suppresses the tendency to segregate. Apparently, the intermetallic compound CuSn_3 becomes relatively unstable in the presence of phosphorus (or phosphides) and dotted line *a-b-c* on the second diagram (p. 45) corresponds to an appreciably lower temperature. This means that the temperature gap between the state of liquid homogeneity and the freezing of the copper matrix has been reduced and that the possibility of segregation is correspondingly lessened.

The foregoing may also serve as one explanation of the often observed fact that tin-containing copper-lead alloys made from scrap display less tendency to segregate than those made of virgin metals.

HEAT CONDUCTIVITY

The measure of the degree to which physical and mechanical properties of copper-lead alloys are affected by the presence of minor constituents depends on the composition of the copper-lead alloy, the type of element added, the procedure followed in producing the casting, the residual amount of the minor constituent in the finished product, and the service conditions under which the bearing is used. A discussion of available evidence and of the theories involved would lead far beyond the scope of this paper. It may suffice to point out that the occurrence of intermetallic and semi-metallic compounds, particularly when present in the copper matrix in the form of precipitates, tends to reduce the resistance against impact and fatigue. The effect of these precipitates is largely determined by their size, distribution, and physico-chemical characteristics; restricted amounts of finely dispersed compounds of high melting points may serve as crystallization centers and thus exercise a beneficial effect on the grain size of the casting.

Heat conductivity is of special importance to bearings and this property is often materially affected by the minor constituents. Most commercial copper-lead alloys are of such a composition that the copper matrix forms a skeleton or net which more or less encloses the dispersed lead matrix. Assuming uniform dispersion, the thermal as well as electrical con-

ductivity of the alloy will principally depend on the amount of copper present and on the conductivity of this continuous copper matrix.

To illustrate this relation, Skowronski's diagram of the effect of minor constituents on the electrical conductivity of copper has been reproduced. All elements which form solid solutions with copper lower its conductivity.

The increase in conductivity which some of the elements show is only apparent, as the amount added and not the *residual* percentage has been plotted against the conductivity.

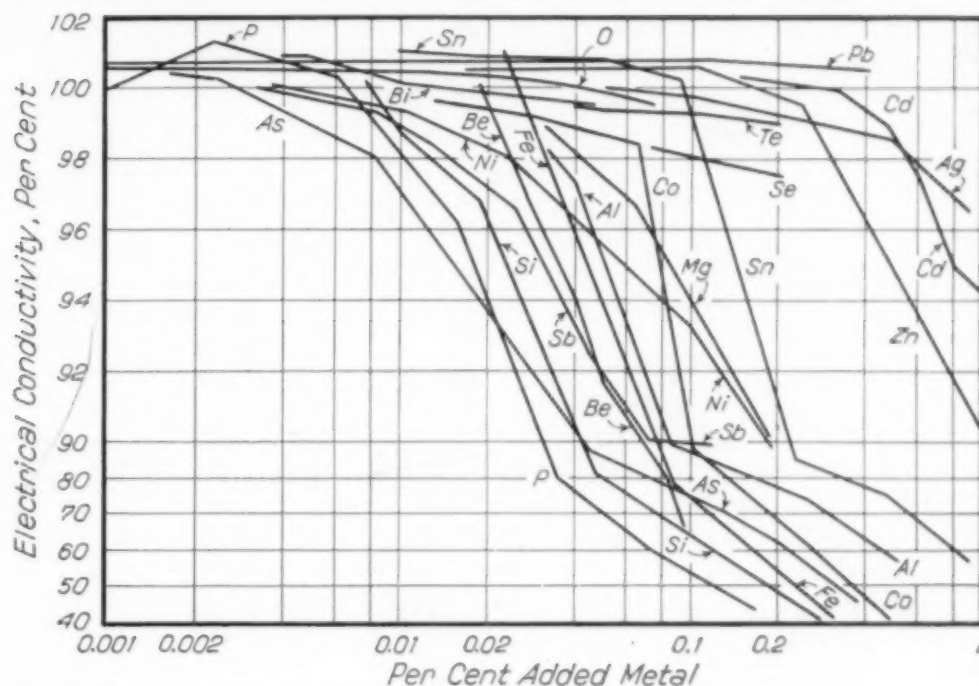
The small amount of lead which the copper matrix holds in solid solution (less than 0.02%) has an almost negligible effect on the conductivity of copper. Straight copper-lead alloys to which no additions have been made should therefore possess the highest conductivity. That optimum is seldom attained as commercial alloys often contain or pick up during the steps of melting and casting contaminations which strongly depress the conductivity. Furthermore, even the purest copper and lead need some deoxidation and degasification, and at this point a detrimental agent may be used.

The most widely used "deoxidizer" is phosphorus. While its addition to solid solution bronzes (which have a low conductivity anyway) is in order or even beneficial, copper-lead alloys of higher conductivities should not be treated with phosphorus. A thorough-going deoxidation — which is absolutely essential — requires the addition of an excess, and an excess of phosphorus will strongly depress the conductivity. Should it not, it is almost certain that deoxidation has been incomplete.

It seems, therefore, logical to use an agent which has no solid solubility in copper. Purifying agents which meet this requirement are pure carbon monoxide, lithium, lithium-calcium alloys, boron and calcium boride (the *element* calcium is soluble in copper). Lithium and lithium-calcium alloys are, incidentally, instrumental in removing refractory oxides like SnO_2 from bronzes, and their respective solid solubilities in lead are great enough to avoid harmful precipitated intermetallic compounds.

Among the elements which promote homogeneity in the miscibility gap, nickel strongly depresses the conductivity. The effect of a small amount of silver is negligible and even in case of higher additions only moderate. Silver offers the additional advantage that it raises the recrystallization temperature of copper comparatively more than other minor constituents.

Small Amounts of Elements Entering Solid Solution With Copper Have a Large Amount of Influence on Electrical (and Heat) Conductivity. Diagram by S. Skowronski, as quoted by Wyman, *General Electric Review*, 1934, p. 123



Presence of sulphur (sulphides) or of oxygen (oxides) lowers the conductivity but slightly.

Solid solution bronzes have, of course, the lowest conductivity of all; Hensel and Tichvinski report conductivities averaging about 16%.

DEGASIFICATION

Two types of porosity occur in copper-lead alloys: (a) Inverse segregation and (b) ordinary unsoundness resulting from incomplete deoxidation. The first can be cured to some extent, the other prevented.

Inverse segregation has its cause in the physico-chemical characteristics inherent to copper-lead alloys. Its *degree*, however, is closely related to minor constituents, whose presence can be aggravating or the opposite. The minimum amount of inverse segregation depends on the difference in contraction on solidification of the two matrices; contraction of copper is about 12% greater than of lead.

Liberation of dissolved gases on freezing can produce inverse segregation in its most severe form. Contrary to other metals and alloys whose liquidus and solidus lie close together and which liberate gases almost instantaneously, the wide "mushy stage" in high lead-copper alloys liberates the gases rather slowly, thus gradually building up gas pressure and forcing the still molten metal into the fine fissures between the solidified copper matrix

crystals. In its extreme case, this process results in the well-known "sweat." In any case, it changes the composition of the alloy in spots, that is, affects uniformity and causes porosity.

As the amount of gases dissolved in molten copper and lead increases with rising temperature, overheating aggravates this inverse segregation. Also, certain minor constituents with high affinity for gases increase the solvent power of the base metal for gases and enhance the inverse segregation.

In copper-lead bronzes containing tin, whose temperature range between liquidus and solidus is shortened, conditions would be more favorable for reducing the degree of inverse segregation were it not for the obligatory overheating which entirely eliminates that advantage. On the other hand, no serious inverse segregation has been reported for copper-lead bronzes containing manganese, which is not surprising as no overheating is necessary.

It is obvious that the removal of most of the gases—whose principal constituent is hydrogen—is essential before pouring begins. "Washing" the molten metal with inert gases like nitrogen and carbon monoxide, or treating with certain gaseous halides (TiCl_4 , BCl_3) which are thermally decomposed in the molten metal and react with hydrogen, has been used with success in other metals, particularly in copper and aluminum. Applied to copper-lead

alloys, the stirring effect of the gases would promote homogeneity; however, accurate temperature control would be more difficult.

Hydrogen has been removed quite simply by treating the molten metal with agents capable of forming insoluble hydrides which have a higher heat of formation than the gas-metal solution. The most stable of these "salt-like" hydrides is lithium hydride. It has a melting point of about 680° C. (1250° F.) and a specific gravity of about 0.8.

Deoxidation and degasification are at present quite well understood, thanks to the systematic efforts of the British Non-Ferrous Metals Research Association. British investigators, among whom Allen and his classical work is here of particular interest, have shown that in the absence of oxygen (oxides) porosity occurs in the above discussed form of segregation (inverse or common) and produces relatively large hydrogen cavities. Residual oxygen alone does not cause porosity. It is the simultaneous presence of small residual amounts of oxygen and hydrogen which causes steam pockets or pinhole porosity. Equilibria of reactions between oxidizing and reducing agents have been studied in Great Britain and clearly indicate that appreciable amounts of oxygen and reducing agent are coexistent in the molten bath for a long period of time. As small residual amounts of hydrogen—which hardly can be avoided—cause relatively little trouble, complete deoxidation is essential. The latter can be achieved by reasonably overdosing with the deoxidizer.

In conclusion, it is shown by a number of examples that the presence of undesirable as well as the addition of supposedly desirable minor constituents creates a variety of problems. There is ample evidence that minor constituents can produce distinctly beneficial effects in copper-lead alloys, but a careful analysis of all conditions involved, including the physical chemistry of the minor constituent, is necessary. The attempted classification of minor constituents is based on relatively meager evidence, and this paper will have served another purpose besides the one stated in the beginning if it should stimulate more and more fundamental research on the subject. There is no doubt in the mind of the writer but that well-planned and organized efforts in that direction should ultimately simplify production methods, assure better uniformity in quality and reduce all-around costs.

TRENDS IN THE NON-FERROUS FOUNDRY*

BY L. B. HUNT

THE OBJECTIVES in all foundry work may be taken as improvements in soundness, strength and economy. Let us appraise these factors under four headings.

Materials—The outstanding improvement in purity of the primary metals is the production of 99.99% zinc for die castings, for oxygen-free copper and high purity aluminum have not as yet found any foundry applications.

Internal competition among the primary metals is a factor worthy of some consideration—for example, the growing use of aluminum alloy cylinder heads for gas engines and the proposals to use high conductivity copper alloys containing a small percentage of chromium.

Considerable interest is being taken in the possibilities of using materials other than sand for molds. The Randupson process, employing a weak type of concrete, gives a more rapid rate of solidification than sand, and a greater permeability. Investigations of several plastic molding compositions show that the commonly used sands have low thermal conductivity, and it is a practical proposition to produce plastic molding compositions having a conductivity superior to that of steel and almost equal to that of copper. Such mixtures, based upon graphite or carborundum, with additions of bentonite and a liquid binder, can be used repeatedly.

Methods—"Sanitary metallurgy" will produce sounder castings as our knowledge of the precise action of degasifiers and fluxes improves. Molten metal should be actually shaken up with solvent fluxes, and it is apparent that the efficiency depends largely upon intimate mixing, whether or not such shaking is resorted to. Professor Hutton has suggested the actual filtration of molten metals, and while this may be more suited to the production of billets for rolling, it is a foundry possibility.

Casting methods for ingots and billets of aluminum and copper have received considerable attention, and a number of improved methods have been evolved to insure the slow and steady flow of metal into the mold. The foundry, however, still clings to methods that have been in use for generations, although it appears to be a reasonable assumption that mechanized pouring, suitably modified from those

(Continued on page 94)

*Abstract of paper for Annual Conference, Institute of British Foundrymen, 1937.

Economists have been telling us that if only the construction of small houses could be in some manner resurrected, it would be the spark plug of a general forward movement that would lift all industry far

out of depression or recession. Metallurgists believe that the adaptability and reliability of metal has not been properly appraised by owner and architect; otherwise cheaper but less durable building mate-

rials would never be considered. When, as and if the building boom arrives, light gage, flat rolled steel has already proven its competence in house construction, both for the framing and the covering.

OPENHEARTH IRON

TAPS A NEW MARKET

BY CHARLES S. PEARCE, WASHINGTON, D. C.

AMID the numberless promotional articles about metal houses appearing recently in the daily press (not to mention magazines in the architectural and metal field) one fact is emerging—that the idea is really being translated into action. Of all the hundred or more proposed designs, about a score have been reasonably successful, and well along toward 2000 residences constructed. Even a larger number of filling stations and small restaurant buildings have also appeared, where glass and metal (either bright or enameled) are the major materials of construction.

Some enthusiasts have pointed to the metal house as the one new industry which will be responsible for our next industrial and economic up-surge. Of course, this has not yet transpired; nevertheless the experiences so far have been exceedingly useful to all concerned in sifting the good ideas from the not-so-good, and in accumulating a fund of information on all phases of production—manufacture, erection and sale.

Metal for housing has two broad subdivisions—framing and covering. Frames are essentially adaptations from the skeletons of large buildings, and the subject is, therefore,

fairly well understood by engineers, architects and owners. Covering—metal on exteriors—is not so well appreciated. The questions of durability and finish have been solved in such places as ornamental store fronts by the use of copper and bronzes, aluminum, chromium plated steel, stainless steel, enameled iron, and (less frequently and satisfactorily) with painted steel sheet.

In ordinary residences the cost factor is a much more important consideration and must not be ignored. Optimum results as to cost, durability, and finish now seem to be possible with the use of enameled iron panels. It presents the architect a beautiful surface in a range of shapes and colors never before attained. It presents to the home owner a well-known material—long used on domestic utensils, stoves, bath tubs, and (with the mechanization of the home) refrigerator cabinets and washing machine tubs. He does not need to be sold on its ability to resist extremes of heat and cold, or its durability and sanitary features.

Enameled iron sheets have been used in a small way for architectural purposes for years. In 1893 a bold attempt was made to introduce this material to builders when a house of



enameled iron was erected in Germany. However, the use of enameled sheets did not take hold; it remained for this structure to act as the proving ground to which we can now look back for an example of durability.

After the War, shingles of iron (that is, openhearth iron or ingot iron) with an enamel finish were developed. These came into general use by 1925, especially where a durable yet colorful roof was desired. Today they are an accepted part of commercial building construction, and are used by various companies to identify their places of business. The oil industry was the first to make extensive use of such roofs, and concerns in this field soon found that enameled sheets also made good exteriors for filling stations. During the early depression years the porcelain enameled filling station became a common sight. Today it is a standard method of construction with many oil companies.

1929 to 1933 saw many feeble attempts to popularize enamel as a building material, but it remained for the showing of the porcelain enameled houses at Chicago's Century of Progress

New Research Laboratories of The American Rolling Mill Co., Middletown, Ohio, Dedicated Nov. 5, 1937. Designed and erected by The Austin Co., Harold Goetz, associate architect. As shown by the adjoining wall section, the rivetless frame uses many shapes formed from strip. Details have been proven by use in at least 250 sheet metal residences and commercial buildings constructed by Steelox (an Armco subsidiary). Exterior is resplendent in canary colored ("yellow satin") enameled panels set with jet bitumen joints, horizontal stainless steel striping, and clear glass blocks

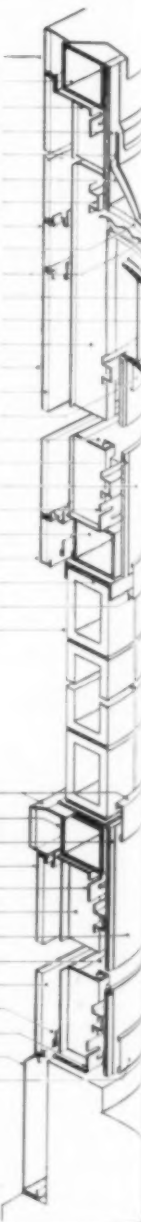
Exposition to focus attention on this material. Since then developments in the commercial field have been rapid.

Complete buildings are now designed for the use of enameled sheets as the finished surface, and many commercial buildings are being remodeled with its aid. Its value in this field lies in the use of color, permanency and easy cleaning. Drab buildings of older construction can be given new life with an attractive facing of colored porcelain. In the field of special buildings, the restaurant trade has recognized the advantages of color and durability. Many eating places, especially for construction in the outlying sections of cities, are being constructed of iron sheets with a finish of white or highly colored enamels.

And finally, to crown the latest development, one of our large steel companies has constructed a new

Stainless coping
Hot rolled tubing
"Steelox" angle
Plywood
Roofing
Metal cant strip
Metal furring
Stainless steel
Insulation board
Corrugated sheet
Steel roof panels
Cork insulation
Steel wall panels
Porcelain enamel
Insulation
Stainless steel
Rock wool
Plywood
Furniture steel
"Steelox" angle
Hot rolled tubing
Stainless steel
Caulking
Stainless steel
Glass blocks

Stainless steel
Hot rolled tubing
Plywood
Porcelain enamel
"Steelox" angle
Steel wall panels
Furniture steel
Rock wool
Insulation
Girts
Steel base angle
Macotta base
Stainless steel



research laboratory finished with canary colored, enamel sheets set off by stripes of stainless steel. This building, with its all-welded frame and extensive use of glass blocks in side walls and skylights, is the last word in modern industrial architecture.

As porcelain enamel has been adopted as an exterior finish for buildings, its use in other special fields of architecture has been growing. For instance, there will soon be erected in the city of Washington an apartment house with enameled iron spandrels; 161 of these pieces, each 3x5 ft. and weighing about 40 lb., will fill the vertical spaces between the storied windows. A brilliant shade of blue with yellow decorations will enhance the beauty of this building.

ENAMELED PANELS ON STONE

Another development that promises wide application in the building industry is blocks of artificial stone faced with enameled panels. This method of building has been in use long enough to be thoroughly proved, and recent tests at the Bureau of Standards have shown them to be the equal of stone. Not only are these blocks easy to erect, but they will be acceptable where panel type of construction might not conform to building codes. They will also furnish the designer of buildings a wide range of colors formerly unavailable in other materials.

When buildings are faced with enamel, it seems only natural that signs should be made of enamel too. This branch of the enamel industry is one of the oldest, porcelain enameled signs having been made for nearly half a century. It is now enjoying new life as the demand for letters for neon displays grows apace with the erection of new commercial buildings. In combination with stainless steel and bronze, enameled iron builds up a fine display.

With the exteriors of commercial buildings and signs made of enamel, it is natural to expect that new uses will be found for porcelain panels on the interiors of commercial buildings. Not only can it be made exceedingly attractive, but is, of course, a durable material, highly resistant to acid fumes and greasy smoke. This is especially important in kitchens, restaurants, and laboratories, bakeries and hospitals; even the Post Office Department has found that enameled iron is desirable for the interior of dark buildings where side walls must reflect as much of the light as possible.

But as the usage of enameled iron panels on buildings develops, new problems are encountered which demand the attention of the metallurgist as well as the ceramic engineer. Building units are different from parts for mass production products such as refrigerators and stoves. In the building industry, all pieces are made to order and very few are duplicates. This means that shapes must be completely laid out in drawings, *accurately* fabricated before delivery to the job, and in general, this fabrication must be largely by hand methods. This means that the problems of high grade sheet metal work must be met at the very outset.

Small flat panels are routine, but simple radius pieces, and pieces with compound curves are very difficult to make so they fit correctly each to each. Bent pieces of this sort must be specially supported during the firing operation — sometimes not an easy matter. As production increases, standard bends can be formulated and it will then be economical to construct forming dies and special furnace cradles. Meantime, the architectural designer and the enameler must both attempt to find a mid-point where an improved shop technique will produce the redesigned details with the minimum cost.

This problem is further complicated by the lack of a universal method for attaching panels, and of standardized methods of erection. Erecting crews trained to handle enameled sheets must be organized and carefully instructed in new methods.

Fabrication to exact dimension must be completed in the shop, as alterations on the job are not satisfactory. Bare edges rust, and chipped places in the enameled surface violently detract from the beauty of the finished building. If a part does not fit, it must be reordered, and this means a delay of two days at least.

WAVINESS A SERIOUS DEFECT

One of the most important challenges to the enamel industry, and of course, also to the steel industry, is the waviness of large panels. Porcelain enamel on sheet steel has not yet been made with this serious defect eliminated, although many things have been done to minimize its effect. Of these improvements, non-sagging metal is as important as a low burning ground coat. Heavy gage of base metal is still the recognized method for producing panels of reasonable smoothness, and practically all structural work is done in 14 or 16-gage iron.

These demands for building shapes of good quality raise the question of what the industry must have in a good enameling sheet. Of great importance is the matter of gage. Too much stress cannot be laid on the use of sheet heavy enough to be properly fabricated and heavy enough to withstand the normal abuse that it will receive in transportation, erection and ordinary life.

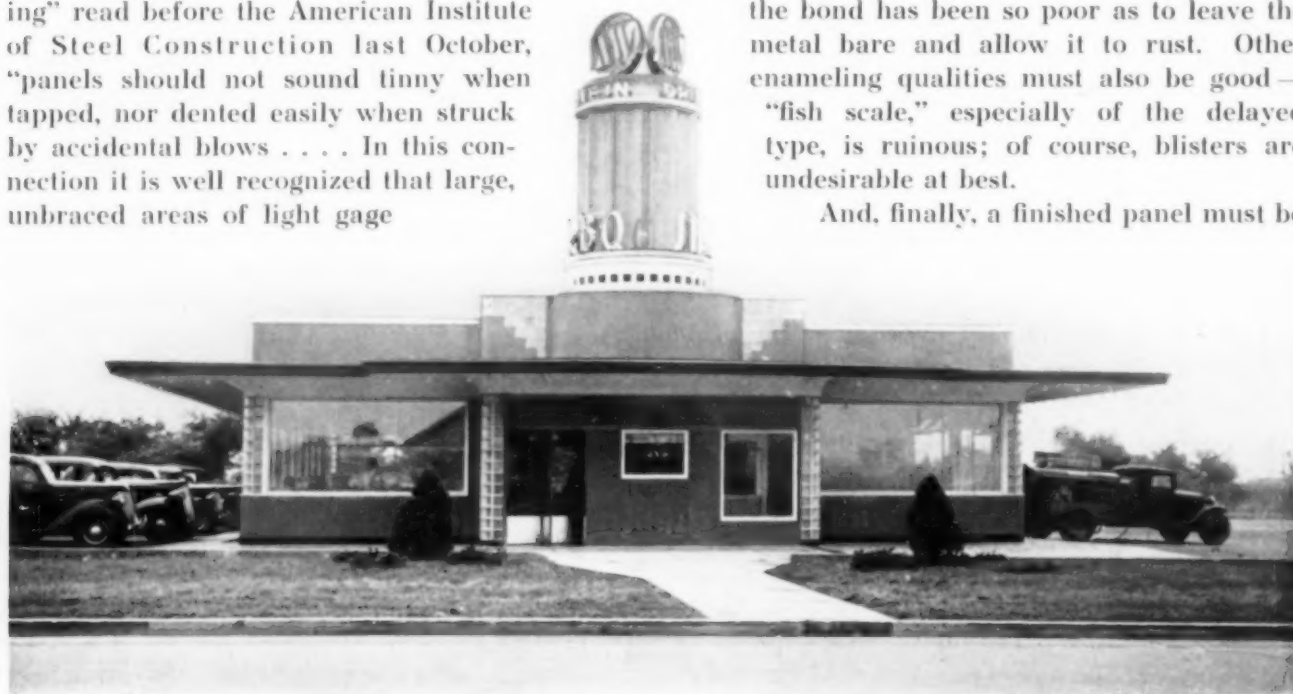
No rules for gage determination have been developed yet, but safety on the side of heavy metal is desirable. As pointed out by F. T. Llewellyn in his most excellent resume of "Light Gage, Flat Rolled Steel in Housing" read before the American Institute of Steel Construction last October, "panels should not sound tinny when tapped, nor dented easily when struck by accidental blows In this connection it is well recognized that large, unbraced areas of light gage

forming dies cannot be constructed for such a wide range of shapes.

With such hand forming methods, welding becomes a very important consideration. Bare sheet metal must weld easily and smoothly with inexpensive preparation. A minimum of imperfections in the weld is allowable, as most joints must be enameled on the outside, and must present a finished appearance.

Another consideration is good enameling properties, especially good adherence. Nothing can so detract from a beautiful piece of enameled iron as a place where the enamel coat has left the metal. This is especially serious where the bond has been so poor as to leave the metal bare and allow it to rust. Other enameling qualities must also be good — "fish scale," especially of the delayed type, is ruinous; of course, blisters are undesirable at best.

And, finally, a finished panel must be

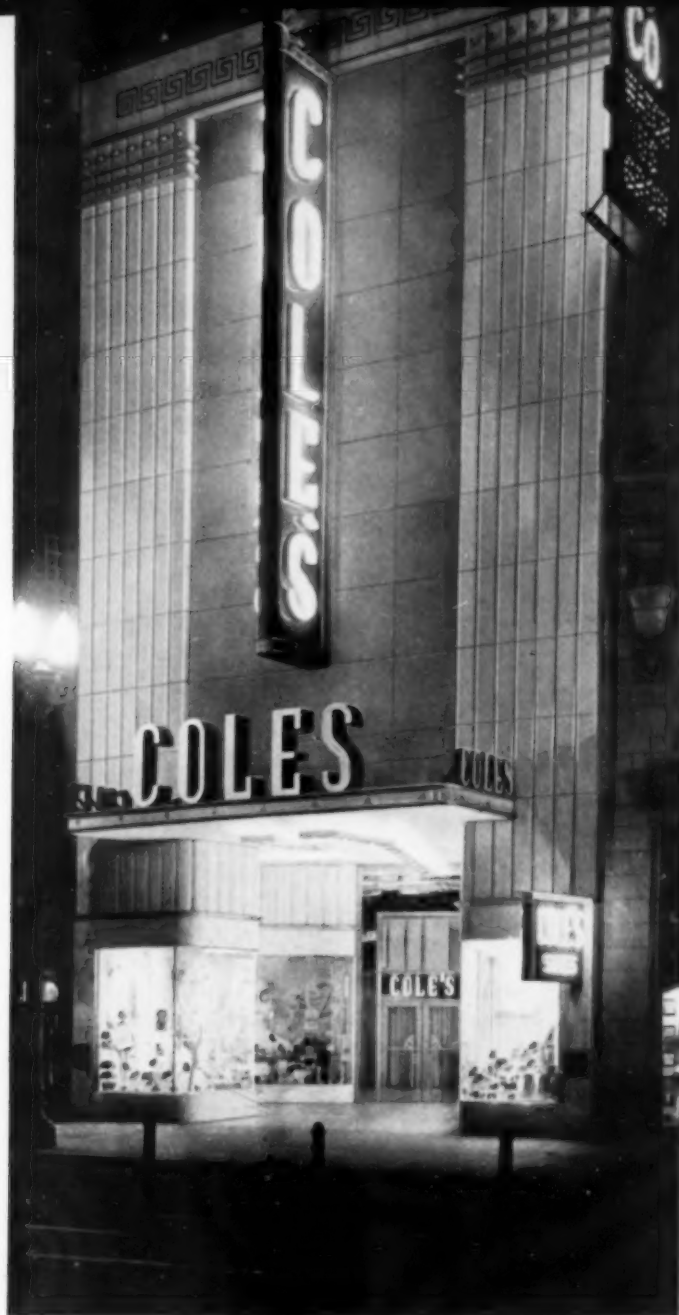


Fine Example of Roadside Restaurant Erected Near Washington, Utilizing Porcelain Enameled Iron and Glass for Exterior and Interior

will buckle when subjected to flexural and compressive stresses." He proposes a tentative basis for design that should be useful. When one boundary is stiffened and one free (as the flange on a panel), its width should be no more than ten times the thickness. When one boundary is stiffened and the other fixed (as the sides of a pan whose upstanding edge is also flanged), the width should not be more than 30 times the thickness. The width of panels, whose edges are flanged (fixed) or continuous across a stud or internal brace, should not be more than 100 times the thickness.

Returning to a consideration of the qualities of metal desired, the forming properties must be good, as many operations are done by hand, or with very inexpensive tools. Intricate

as near dead flat as possible. This has been discussed before, but it is important enough to repeat. Waviness of enameled structural panels may spoil the use of this material in the entire architectural field. Pure iron as now made for enameling purposes is the best material to hold its shape in firing, but even this is not good enough. Metallurgists say that the reason is associated with the fact that ingot iron is so free from carbon that there is no pearlite to transform on heating past Ac_1 — the metal remains as ferrite even as high as $1650^\circ F.$, beyond the firing temperature, and thus ferrite is far stiffer when hot than low carbon steel which has a substantial amount of more plastic austenite in the same range between Ac_1 and Ac_3 . The problem of greater inherent stiffness at firing temperatures



Front of Five-Story Building in Cleveland Modernized by Porcelain Enamel on Sheet Steel. White fluted columns and brown trimmed lintel frame a center section of yellow Verona marble. Ceiling of canopy and entry also of white enameled steel

able than a variation in color, panel to panel. For this reason it is often necessary to inspect these parts after assembling a large number against an outer wall. In this manner any variation can be easily spotted and the offending panels recoated to bring to correct color and tone.

If the steel industry and the enamellers meet the demands of the building trade for satisfactory structural porcelain, the consumption of iron sheets will rise to a new high level. This really is necessary if the continuous sheet mills are all to be kept reasonably busy. Mr. Llewellyn's studies developed average figures for design systems using light gage steel for residences as reproduced in the small table below. Even small buildings may therefore use two or three tons of sheets for their outside surfaces. The expanding uses of porcelain enamel in all phases of the architectural field will increase this usage per building. If proper gages are demanded for 100% durability, the tonnage will go even higher.

The metal building of today is handicapped by only one factor — exterior finish. Rust will quickly deface and eventually destroy any common steel or iron sheet used for exterior work unless it is properly and permanently protected. Porcelain enamel is the one material that gives life-long protection to the iron sheet, and so opens the way for extensive building uses.

The coming years will see an increase in building that will dwarf the post-War boom. Buildings will be erected in great numbers — especially residences must be constructed to make up for eight years of stagnancy.

If porcelain enamel is adapted to houses as it has already been adapted to commercial structures, an outlet of undreamed-of magnitude will be developed.

Pounds of Steel for Residences

	FRAMING	COVERING	FRAMING & COVERING
Per sq.ft. wall	1.45	3.80	5.25
Per sq.ft. floor	2.05	2.50	4.55
Per room	2000	3000	5000

should be an immediate challenge to the metallurgists of the industry.

Meanwhile, the enameler does what he can by increasing the gage, enameling both faces equally, hanging the pieces during firing, and using ripple and matte finishes. One can sometimes depend on a stiff backing of block insulation, where this must be installed anyway, but otherwise it is too expensive a cure. At any rate, until architectural enamel, in broad expanse, becomes less wavy, competitive materials can always point the finger of scorn.

Second only to the problem of warpage and waviness is that of color variation — although not nearly as difficult to solve. A. C. Weirich discussed this at some length before the recent Porcelain Enamel Institute Forum. When an architectural installation of porcelain enamel is viewed from a distance, nothing is more notice-

In METAL PROGRESS, two months ago, Mr. Case described means of determining the sensitivity of steel to the effects of cold work. For that purpose he relied on the Izod impact

test, a test unduly influenced by accidental variations in metal or testing conditions. Damping capacity of a metal is known to be greatly influenced by previous overstrain, and its

larger test piece is free from the above limitations. Investigation reveals it to reflect very precisely the aging characteristics of steel—a matter indicative of expected performance.

DAMPING CAPACITY AND AGING OF STEEL

BY S. L. CASE, JONES & LAUGHLIN STEEL CORP.
Metallurgist, Research and Development Division

IN 1932 H. W. Graham read a paper before the Iron and Steel Institute entitled "A Modern Conception of Steel Quality." This paper, in order not to extend its length unduly, was confined primarily to the theoretical aspects of "sensitivity." The paper published two months ago by Mr. Case in METAL PROGRESS, along with the present one, is designed to give facts and figures supporting and extending the ideas originally presented by Mr. Graham in 1932.—
EDITOR'S NOTE.

* * *

Investigations on low carbon steels have indicated that conventional tests for metal quality—such as chemical analysis, metallography, tensile strength, impact, and hardness—are incapable of distinguishing heats of steel which have quite different aging characteristics. It was suspected that the aging characteristics were related to the embrittling effect of cold work. To get a quantitative idea of this last-mentioned property, the "work sensitivity test" described by the writer in the November issue of METAL PROGRESS was devised. It is made thus: A bar turned to standard taper is drawn through a round die (thus producing a gradual incre-

ment of cold work, end to end) notched at uniform intervals, broken at these places on an Izod impact machine, and the energy loss plotted against the per cent reduction of area previously imposed by the drawing operation. The course of this "work brittleness curve" indicates whether the steel is sensitive or insensitive to cold work.

In a critical appraisal of this test it is essential to bear in mind that the measurements are made in terms of Izod impact toughness. Such a test is therefore subject to the limitations of an Izod test—that is, an occasional scattering of points due to local segregation, blow holes at or near the notch, and variables associated with heat treatment.

EVALUATION OF DAMPING CAPACITY

Corroborative evidence based on a test that should not be subject to such influences is therefore highly desirable. Such evidence is furnished by measurements of a property which is little influenced by heat treatment, and, due to a comparatively large volume of steel involved in the test, is not appreciably affected by either localized segregation of impurities, blow holes,

or mechanical defects. Such a property is damping capacity. The nature of this property and methods of its evaluation in the laboratory will now be discussed.

As the precision of instruments and equipment used in physical testing of materials is being raised to a higher and higher plane of accuracy, it becomes clear that Hooke's law, stating that in the elastic range stress is directly proportional to strain, is not as scrupulously obeyed by metal as one had been led to believe. The Germans Becker and Föppl subjected steel specimens to completely reversed cycles of axial stress in a static machine (tension and compression), and found that although the stresses applied were well within the elastic range of the material, the stress-strain curves did not form a straight line, as they should have if the material obeyed Hooke's law, but formed a series of loops similar in shape to the well known magnetic hysteresis loops, and termed, therefore, elastic hysteresis loops. The area of such a loop, formed by a completely reversed cycle of stress, represents energy dissipated by the specimen in the form of heat, and serves as a measure of the internal friction of the material for the particular stress involved.

The generally accepted term for this internal friction is "Damping Capacity" which was defined by Föppl as "the amount of work dissipated into heat by a unit volume of the material during a completely reversed cycle of stress." Herr Föppl, who is director of the Wöhler Institute in Braunschweig, summarized this and more recent work in Germany in an article in English for the British Iron and Steel Institute in 1936 (abstracted in METAL PROGRESS last September) which is doubtless much more convenient for reference by American readers.

While the damping capacity of a given material can be thus accurately determined by plotting accurately the areas of elastic hysteresis loops obtained on a tension and compression test, such a method requires unusual precision not readily available in the average laboratory. The width of an elastic hysteresis loop is less than one millionth of an inch per inch, and the accuracy of an ordinary strain meter is not sufficient to measure such differences. Other methods, such as a measure of the increase in the temperature of the specimen during fatigue testing can also serve to evaluate the damping capacity of the material.

However, a rapid and practical method, which was used in the preparation of the data

assembled in this paper, is the "free vibration method" in which the specimen performs free torsional vibrations which are damped only by the internal friction of the specimen. In such tests the specimen acts as a spring of an elastic oscillating system, which vibrates in its own



Elastic Hysteresis (Damping Capacity) Can Be Measured by Precise Extensometers, as This One Sensitive to 0.00,000,005 In. Courtesy P. G. McVetty of Westinghouse

natural frequency without external impulses. A definite initial displacement of the mass is applied in order to give the specimen the desired degree of stress; the system then oscillates due to its own internal forces. The amplitude of vibration gradually decreases until the potential energy of the system, put in by the initial displacement of the system, becomes completely dissipated.

SIMPLIFIED TESTING EQUIPMENT

The tests which are being presented here were performed on a Föppl-Pertz vibration damping tester, developed at the Wöhler Institute. A photograph of it is shown on page 56. The frame is suspended on a flexible wire cable so as to isolate it from any external losses of energy, and provide the accuracy needed in determining the comparatively small amounts of work absorbed by the internal friction of the specimen. The vertical test specimen is rigidly clamped at its bottom into jaws mounted to the base of the frame. At the top of the test specimen is clamped a horizontal bar.

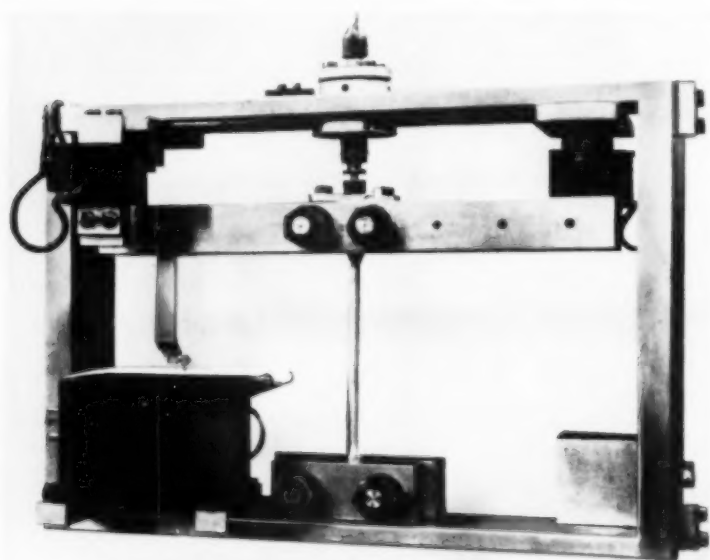
The test is started by moving this bar by hand in a horizontal plane, imposing a desired angular displacement to the top end of the ver-

tical specimen and holding it in this position by means of two adjustable electromagnets, located near the ends of the bar. Upon breaking the circuit of which the magnet bars are a part, a free oscillation is produced. A stylus attached to the left end of the horizontal bar records a free vibration diagram on a clock-driven chart resting on the lower yoke. The immediate results of this test are diagrams like those adjoining the photograph; they clearly illustrate the great variation in the envelope of the curves on specimens showing different degrees of damping capacity.

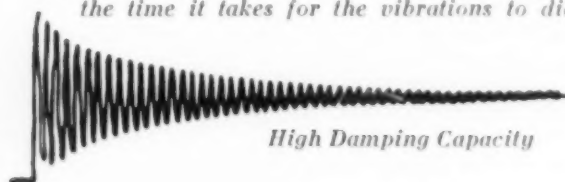
It has been shown by Dr. Föppl that the specific damping capacity of the material is equal to twice the logarithmic decrement of a

effective length of the specimen and a is the amplitude of vibration. In such calculations the average torsional stress rather than the fiber stress is considered, because, unlike a tension-compression test, in a torsion test the stress is not uniform throughout the entire cross-section of the specimen, but varies from zero at the center to a maximum at the surface. It is possible to obtain the correct damping values for the outer fiber stress by means of a very complicated computation or by the use of hollow specimens with thin walls; however, the first method is very tedious and the second impractical, so the *average* damping values for the entire cross-section are generally obtained in the free vibration method of testing.

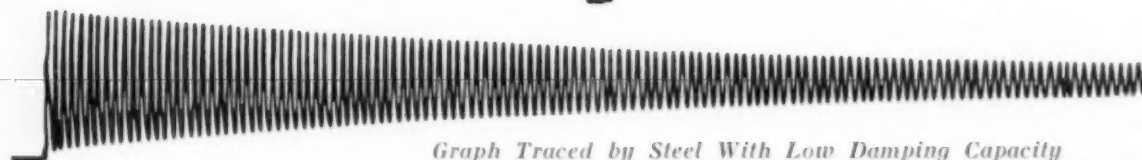
Since the difference in amplitude between two successive vibrations is often too small to be measured, the damping graph is divided into small sections in which the outline of the envelope approaches a straight line, thus indicating a constant decrease in amplitude of



In the Föppl-Pertz Vibration Damping Tester a Vertical Test Piece Is Slightly Twisted, the Restraining Torsional Forces Suddenly Released, and the Dying Oscillations Recorded by Stylus on Paper Tape. Steels vary considerably in the time it takes for the vibrations to die



High Damping Capacity



Graph Traced by Steel With Low Damping Capacity

damped vibration. It can also be shown that this value can be very closely approximated by dividing double the decrease of amplitude between successive vibration by the average amplitude of these vibrations. The average torsional stress corresponding to any given amplitude of vibration may be readily computed from the formula

$$S = \frac{dG}{4rl} a$$

where S is the average torsional stress, d is the diameter of the specimen, G is the modulus of elasticity in torsion, r is the radius of the path of the recording pen in the machine, l is the

vibration. The difference in amplitude between the largest and smallest vibration in such a section of the graph, divided by the number of vibrations in the section, gives the average decrease in amplitude for one vibration. The torsional stress is plotted as abscissa and the damping capacity as ordinate. The resulting damping curve shows graphically the damping characteristics of the material.

From time to time various attempts have been made to discover a possible correlation between damping capacity, grain size, and certain physical properties. R. H. Canfield reported such tests in *Transactions*, 1932, and G. R.

Brophy in *The Iron Age*, Nov. 24, 1932, as well as *Transactions* 9, 1936. The number of steels used by these investigators was comparatively limited. Careful analysis of the treatment to which these materials were subjected discloses a number of variables which were not taken into account. Canfield, for instance, shows a direct relationship between grain size of Armco iron specimens and their damping capacity. These specimens were, however, strain-annealed to develop large grain size and, in view of present knowledge, the straining undoubtedly had an important effect on the numerical results.

Summarizing typical results of the damping capacity tests on over 200 steels of which the background, history and sensitivity characteristics were known, it will be found that they fail to disclose a definite correlation between inherent austenitic or pearlitic grain size of steel and its damping capacity. In plain carbon steels, the effect of chemical composition on damping capacity is also of comparatively minor importance, although carbon and manganese apparently have a general tendency to lower the damping capacity. On practically all steels the annealed state shows the highest damping capacity, the quenched and tempered state the lowest—but the difference is not very striking. In trying to associate damping capacity with static and dynamic tests no clear-cut relationship was found by us.

In comparison with the rather mild effects of variations in chemical composition and ordinary heat treatment on the damping capacity of steel, the effect of cold work stands out in bold relief. The curves at right illustrate a

Analysis of Steels Tested

Mark	C	Mn	P	S
A-1	0.20	0.39	0.014	0.033
A-2	0.20	0.36	0.016	0.029
A-3	0.22	0.35	0.016	0.031
A-4	0.21	0.37	0.012	0.033
A-5	0.17	0.90	0.017	0.021
A-9	0.20	0.34	0.015	0.035
B-2	0.38	0.85	0.018	0.027
B-4	0.39	0.83	0.020	0.025
C-1	0.62	1.14	0.027	0.033
C-2	0.63	1.17	0.024	0.030
C-3	0.61	1.12	0.026	0.032

is not an exceptional case. Cold work invariably raises the damping capacity of steel to levels that cannot be approached by any other treatment. How long this effect persists in overstrained material is a subject which shall be discussed in detail a little later, but it is essential to remember that immediately after overstrain the damping capacity of steel is unusually high. Steel A-2 was known to be "sensitive"—see its work brittleness curve on page 672, METAL

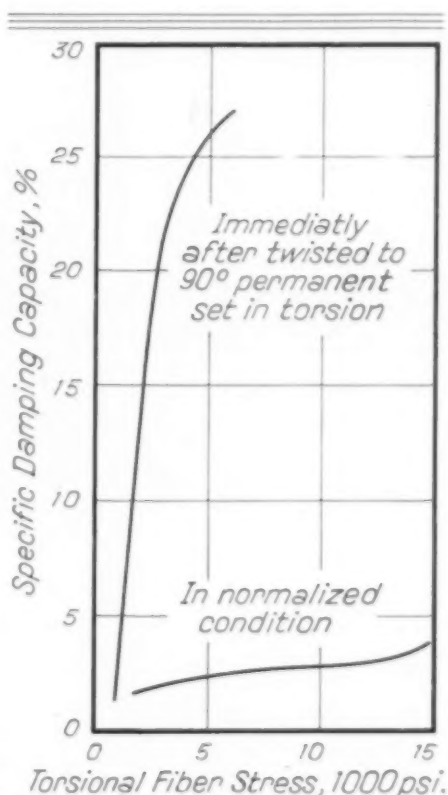
typical condition. This test was made on a test specimen from structural grade Heat A-2 on which damping capacity curves were obtained in the normalized state and after the test piece had been twisted in a torsion machine to a 90° permanent set.

The damping curve of the overstrained test piece shows that the increase in damping capacity due to overstrain is approximately 1000% for a torsional stress of 5000 psi. This condition

PROGRESS for November 1937, but without a single exception all of the large number of steels which were tested exhibited a similar reaction to cold work—their damping capacity was greatly increased.

(It should be noted here that the damping curve of cold-worked material covers a much narrower range of torsional stresses than in the normalized or hot-rolled state. This condition will be observed on all cold-worked tests shown later, and is due to the fact that such tests are made immediately after overstraining, when the elastic range of the overstrained material under torsional stresses is very low.)

Successive work brittleness tests, as has been already shown in the November article, measure the aging capacity and rate of aging of steel in terms of Izod impact toughness, and indicate a certain



Damping Capacity of All Steels Is Greatly Increased by Overstraining. (Specifically, this test was on Heat No. A-2, structural grade, coarse-grained, sensitive to work hardening)

correlation between sensitivity and aging characteristics. Since the damping capacity of steel displays such a sharp reaction to cold work, it is now pertinent to inquire whether or not such a test can furnish new evidence for the study of the relationship between sensitivity and aging characteristics of steels.

TYPICAL RESULTS ON SEVEN STEELS

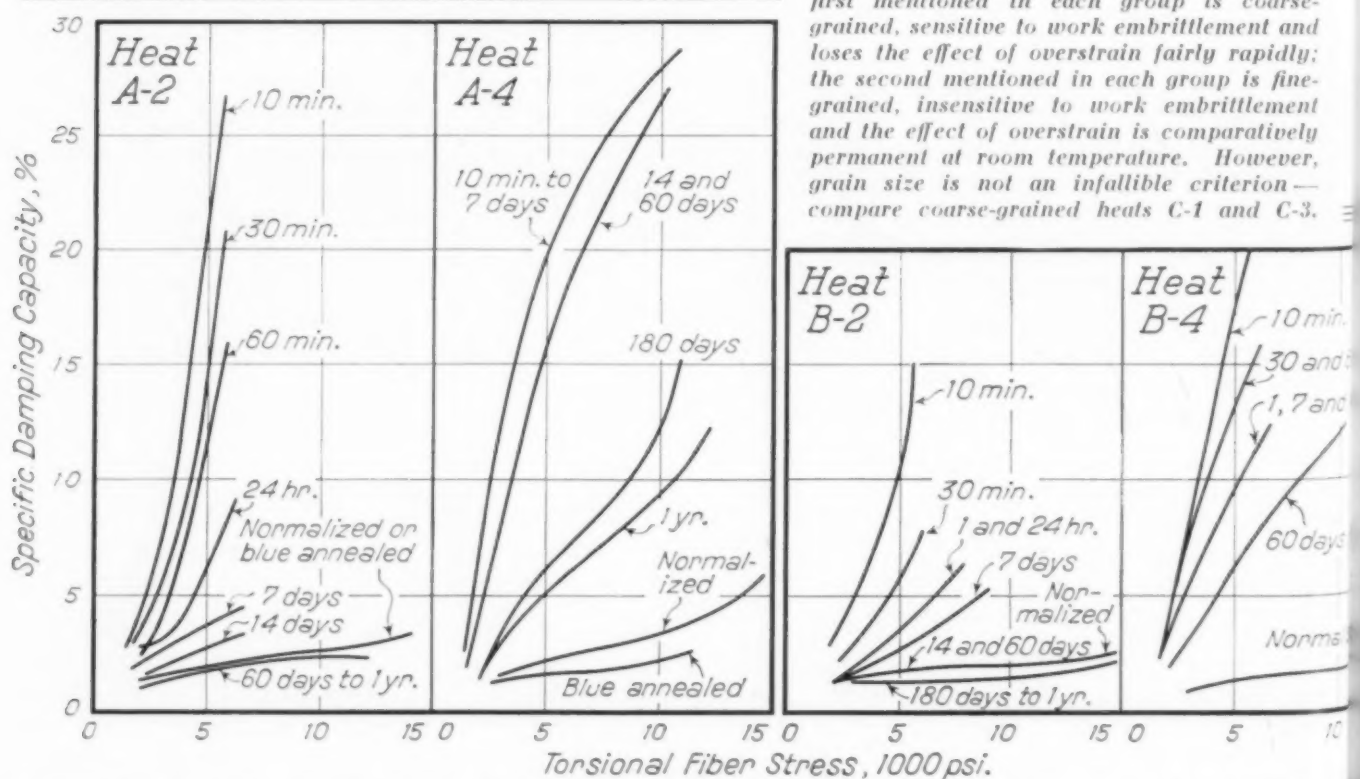
To show this point a series of curves contain the results of tests on seven heats which are typical for 50 lots of carbon steel, of a wide range of analyses, and on which extensive aging tests were conducted. The composition of steels selected is given in the table on page 57, repeated from the November article, and represents three groups consisting of low carbon, medium carbon and high carbon steels. In each group, the chemical composition is almost identical, within the range of analytical error. On each steel, the damping capacity was determined in the normalized condition, then at definite times after cold working the test specimen by twisting it to a 90° permanent set, thus giving the results of aging at room temperature for certain intervals from 10 min. up to one year.

In the first pair (Heats A-2 and A-4) are shown results of duplicate damping tests after accelerated aging at 500° F. (blue annealing).

All such tests proved conclusively that blue annealing lowers the damping capacity to the approximate level of the normalized state. Since such tests did not possess any selectivity, they were not included on the other graphs.

Results of work brittleness tests given previously (METAL PROGRESS, November 1937, page 673) might seem to point to the coarse-grained steels as being sensitive, while the fine-grained steels are insensitive. The aging graphs tell their own story. On all steels the damping capacity is very high immediately after overstrain, but this condition is evidently unstable. The damping capacity is consistently lowered during the course of aging, but at a remarkably different rate for the many sensitive and insensitive steels we investigated.

For instance, the sensitive Heat A-2 shows a considerable drop in damping capacity 30 min. after overstrain; in seven days the damping capacity approaches that of the normalized state; after 60 days aging it is practically the same as in the normalized condition. On the other hand, the insensitive, fine-grained steel, Heat A-4, does not show any aging effects the first seven days, and even after one year of



Damping Tests Clearly Show Extent of Aging of Overstrained Steels. Heats A-2 and A-4 are structural grade; B-2 and B-4 have medium carbon; C-1 and C-2 have high carbon. The first mentioned in each group is coarse-grained, sensitive to work embrittlement and loses the effect of overstrain fairly rapidly; the second mentioned in each group is fine-grained, insensitive to work embrittlement and the effect of overstrain is comparatively permanent at room temperature. However, grain size is not an infallible criterion—compare coarse-grained heats C-1 and C-3.

aging the damping capacity of this steel is twice as great as in the normalized condition.

A similar story is told by the aging tests on medium carbon and high carbon steels, plotted on these two pages.

The three groups of steels point to a remarkable difference in aging characteristics between coarse-grained sensitive steels and fine-grained insensitive steels. For comparison of two coarse-grained steels, the last set shows damping aging tests on Heats C-1 and C-3. Although the grain size on both steels is of the same order of magnitude, their aging characteristics are markedly different. In this case, grain size is evidently not a sufficiently discriminative test. The work brittleness tests of these steels plotted on page 673 of the November issue indicate a considerable difference in the sensitivity of these steels, Heat C-1 being much more sensitive than Heat C-3. As a general conclusion, therefore, one is justified in stating that the work sensitivity and the damping aging behavior of these steels show a correlation which the grain size classification fails to reveal in the case of coarse-grained steels.

CONCLUSIONS

The damping capacity of steel is strongly influenced by cold work. Since work sensitivity

of steel, or the intensity of its reaction to cold work, is measured by the effect of cold work on impact toughness—that is, the work brittleness test, a correlation between the two types of tests may be expected. An analysis of such tests made on a large number of steels, of which typical examples are furnished in this paper, point to the following conclusions:

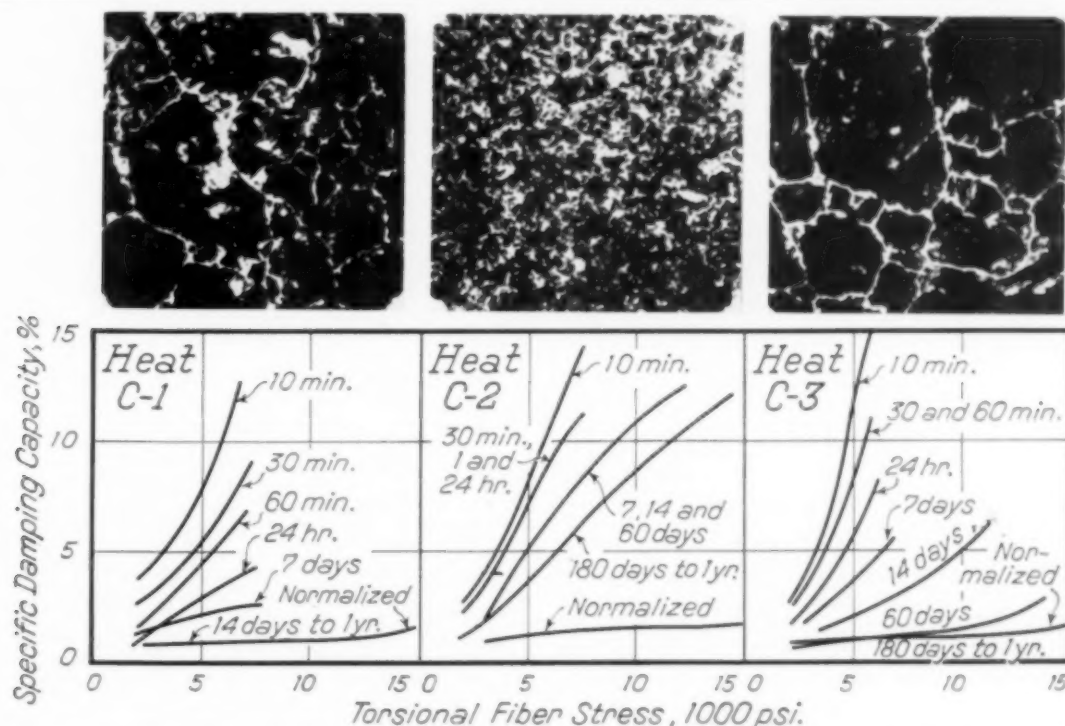
1. Changes in damping capacity of steel, following cold work, serve as a very precise method for evaluation of aging characteristics of the material.

2. The results of the work brittleness test and the damping capacity test show a close correlation when used to measure the aging behavior of overstrained steel.

3. The tendency of steel to age after cold work appears to be closely associated with its work sensitivity.

4. Grain size is not an entirely reliable indication of work sensitivity and aging characteristics of steel. Fine-grained steels show generally a low order of work sensitivity and a low aging rate, but the same properties may vary considerably in coarse-grained steels.

5. Since work sensitivity and aging characteristics of steel are indicative of the expected performance of the material during fabrication and in service, work brittleness and damping capacity tests serve as useful research tools.



If a steel is to machine easily, the principal structural constituent, ferrite, should not be too strong else too much power will be required, not too tough else the chips will not break away freely, and it should con-

tain a multitude of finest non-abrasive inclusions to break up the metallic continuity. Phosphorus is the best chemical element to produce a brittle ferrite; manganese sulphide is the inclusion ordinarily intro-

duced. Cold work is the preferred way to break up the continuity of the ferrite still further which favors a smooth finish, especially if the metal is coarse-grained from finish rolling at high temperature.

IMPROVING THE FREE-CUTTING STEELS

BY J. D. ARMOUR, CHIEF METALLURGIST, UNION DRAWN STEEL CO., MASSILLON, OHIO

WHEN one finds himself investigating the machinability of steels—particularly if he observes machine operations in regular production—he quickly finds so many variables that it seems like a hopeless problem. Merely to list them is sufficient: We have not only the type of machine (whether lathe, automatic, mill) but its condition and the job set-up. The cutting tools themselves have a profound effect—their type, heat treatment, design, sharpness. Then there is the cutting oil, its nature, viscosity, volume, pressure. Finally as to the steel itself, we have the effect of composition, mill practice, heat treatment, cold work.

In an effort to eliminate as many of these variables as possible, we have adopted what might be called a "laboratory production test." Since most of our machining problems have to do with automatic screw machine work, we purchased one of the latest models of four-spindle automatic screw machines. It is shown on page 63. We then designed a part that requires a wide form, a large drill, a small accelerated drill, and a cutting-off operation. Threading taps or chasers, and a knurling operation can also be added to this set-up if desired. This one part, therefore, gives us a test of practically all the operations that are encountered in

automatic screw machine practice. We use an ordinary petroleum cutting oil and high speed steel tools. Tools are ground on a fixture to avoid variations due to grinding by hand.

Since this machine is used for tests only, it gets no more wear in a year than it would in regular production in a month. A large number of tests can be run with one set of tools and the same cutting oil. We feel, therefore, that we have eliminated as far as possible the variables encountered in regular production and at the same time retained the value of an actual production test, and are enabled to compare one lot of steel against another—which latter is, of course, the variable in which Union Drawn Steel Co. is interested primarily. A summary test log is shown opposite.

VARIETIES OF FREE-MACHINING STEELS

While there are only three basic types, bessemer, low carbon openhearth, and high carbon openhearth, each of these basic types of free-machining steels has so many variations that I would not even want to guess at the number that must be manufactured today to meet the demands of the trade.

We have bessemer screw steel with low

Resume of Machinability Tests on Hymo X-1314

Legend: G = Ground tool
NG = Tool needed grinding
p. = Pieces made

Date & Test No.	47/64 In. Drill	1/2 In. Drill	Rough Form	Finish Form	Cut-Off	Face	Total
April 4 90-3134	5615p.(NG) 23 ^h 48 ^m Average: { 5615p. 23 ^h 48 ^m	5615p.(NG) 23 ^h 48 ^m 5615p. 23 ^h 48 ^m	5615p.(NG) 23 ^h 48 ^m 5615p. 23 ^h 48 ^m	5615p.(NG) 23 ^h 48 ^m 5615p. 23 ^h 48 ^m	5615p.(OK) 23 ^h 48 ^m	5615p.(OK) 23 ^h 48 ^m	5615p. 23 ^h 48 ^m
April 19 90-6334	5565p.(NG) 23 ^h 39 ^m Average: { 5565p. 23 ^h 39 ^m	2271p.(G) 12 ^h 26 ^m 3294p.(NG) 11 ^h 13 ^m 2782p. 11 ^h 50 ^m	5565p.(NG) 23 ^h 39 ^m 5565p. 23 ^h 39 ^m	5565p.(OK) 23 ^h 39 ^m	1810p.(G) 7 ^h 41 ^m 3755p.(OK) 15 ^h 58 ^m	5565p.(OK) 23 ^h 39 ^m	5565p. 23 ^h 39 ^m
May 22 90-4130	632p.(G) 2 ^h 41 ^m Drill chipped 5126p.(NG) 21 ^h 50 ^m In bad condition Average: { 2879p. 12 ^h 15 ^m	5758p.(NG) 24 ^h 31 ^m 5758p. 24 ^h 31 ^m	5758p. 24 ^h 31 ^m Slightly in need of grinding 5758p. 24 ^h 31 ^m	5758p. 24 ^h 31 ^m Slightly in need of grinding 5758p. 24 ^h 31 ^m	5758p.(OK) 24 ^h 31 ^m	5758p.(OK) 24 ^h 31 ^m	5758p. 24 ^h 31 ^m
July 3 90-4131	9234p.(NG) 39 ^h 12 ^m Average: { 9234p. 39 ^h 12 ^m	580p.(G) 2 ^h 28 ^m Drill broke, machine trouble 8654p.(NG) 36 ^h 44 ^m 4617p. 19 ^h 36 ^m	1124p.(G) 4 ^h 46 ^m Drill broke, machine trouble 8110p. 34 ^h 26 ^m Tool in fair condition	9234p. 39 ^h 12 ^m Tool still in fair condition Note: Finish on this test was very good	9234p. 39 ^h 12 ^m Tool still in fair condition	9234p. 39 ^h 12 ^m Tool still in fair condition	9234p. 39 ^h 12 ^m
July 27 90-3919	8114p.(NG) 34 ^h 29 ^m Average: { 8114p. 34 ^h 29 ^m	6447p.(G) 27 ^h 23 ^m 1670p.(NG) 7 ^h 6 ^m Tool in bad condition 4057p. 17 ^h 14 ^m	8114p.(NG) 34 ^h 29 ^m Tool in bad condition 8114p. 34 ^h 29 ^m	8114p.(NG) 34 ^h 29 ^m 8114p. 34 ^h 29 ^m	8114p.(NG) 34 ^h 29 ^m 8114p. 34 ^h 29 ^m	8114p.(NG) 34 ^h 29 ^m 8114p. 34 ^h 29 ^m	8114p. 34 ^h 29 ^m

sulphur, high sulphur and higher sulphur. Carbon and manganese have been tampered with some, although not as much as sulphur and phosphorus. In the openhearth steels, we find various manganese ranges all the way from 0.70 up to 2.0%, and this with various combinations of carbon and sulphur. Rephosphorizing has been resorted to in some cases. We also find a wide variation of silicon content from a trace to as much as 0.30%. While some of these variations in chemical analysis unquestionably have merit, we could get along without a great many of the others.

After studying these many varieties by the laboratory production test mentioned at the outset, as well as in regular production, and by correlating these results with microstructure,

grain size, and physical properties, we have gradually built up some theories on what makes free-machining steel machine freely. Perhaps the reader has developed some theories of his own that may not agree with ours, but that really makes very little difference. The important thing is to have some kind of a theory. It will be of inestimable help in diagnosing machining troubles as well as determining a possible solution for the trouble. Build up a theory that will explain all the facts known to you and when you run into some new facts that will not fit your preconceptions, just rebuild the theory to fit the new facts, for the nice thing about a working theory is that it is always subject to change without notice.

It is our belief that the qualities of a steel

that should make it free machining are low strength, low ductility, and the presence of some constituent to break up the continuity of the ferrite. "Low strength" because less power will be necessary for the cutting tool to tear the metal apart; "low ductility" so that the chip will break away more readily once the cutting action is started; and "some constituent" to break up the continuity of the ferrite and give it support so that the tool will be able to cut from one inclusion to the next instead of cutting its way through an unbroken mass of ductile metal.

EFFECT OF PRINCIPAL ELEMENTS

Carbon — We can best observe the effect of carbon on machinability by studying the plain carbon, low sulphur steels. Those with carbon under 0.10% are notoriously poor machining. As carbon increases to 0.15, 0.20, and 0.25%, machinability improves but after we pass about 0.30% carbon, it starts to drop off. This effect is explained, according to our theory, on the basis that with increasing carbon content the tensile strength increases and the ductility decreases; up to about 0.30% carbon, the decrease in ductility aids machinability more than the increased strength retards it. In the neighborhood of 0.30% carbon, however, the factor of increasing strength begins to outweigh the benefits of decreasing ductility.

Manganese and phosphorus also increase the strength and decrease the ductility of steel, and we observe a similar effect on machining properties. If the carbon is under 0.20%, manganese up to about 1½% improves machinability, but when carbon and manganese are raised together, the factor of increased strength quickly overcomes the factor of reduced ductility and machinability decreases.

Within the limits found in commercial steel, or up to about 0.15%, phosphorus improves machinability. This, we believe, is due to the fact that for a given increase in strength we get a larger drop in ductility with phosphorus than we do with carbon.

Sulphur has little effect on either the tensile strength or the ductility in the above sense. Its effect comes from a multitude of small inclusions of manganese sulphide which support the ferrite when it is subjected to the pressure of the cutting tool and allow the tool to cut from one inclusion to the next instead of forcing its way through the solid ferrite. I like to compare the effect of manganese sulphide in steel to a

large block of rubber filled with small shot. Clean rubber would be very difficult to cut; with the shot present, however, the knife can cut from one shot to the next with relative ease. We believe that the sulphide particles that are submicroscopic, or at least *very* fine, play a more important part than those that are readily observed at 100 magnifications. It may also be remarked that other non-abrasive inclusions, such as manganese oxide, are equally effective in this respect.

Silicon — We have not been able to find that silicon improves the machining properties of high sulphur free-machining steel under any conditions. It can be decidedly detrimental if the melting practice has been such that many silicate inclusions are present in the steel.

How should we go about determining the best combination of these elements to get the maximum machinability?

OPTIMUM COMPOSITIONS

Since the relation between sulphur and machinability is a straight line function, the sulphur content will be determined by quality requirements on the one hand, and rolling mill difficulties on the other hand. But, as we have pointed out, sulphur has very little effect on the ductility factor and we must do something about this ductility if we expect to get the maximum in machining qualities. Carbon, manganese, and phosphorus all reduce the ductility and increase the strength and, of course, we are bound to have some of all three in our steel, but the question is "Which one, or ones, can we augment to best advantage from the standpoint of machinability?" Either manganese or phosphorus is preferable to carbon, for they are solid solution elements which embrittle the ferrite while carbon is not. Since phosphorus causes more embrittlement for a given rise in tensile strength than manganese, phosphorus would be our selection if we are to consider machinability alone. For bessemer free-cutting steel, which is designed primarily for maximum machinability, we should therefore keep carbon as low as possible, manganese just high enough to take care of the sulphur comfortably, phosphorus around 0.10%, and sulphur, as mentioned before, as high as possible, depending on quality requirements and the limits of satisfactory mill practice in hot rolling.

For the low carbon, openhearth, free-cutting steels, other factors come into play which

usually make manganese the favorite over phosphorus. These steels are used very largely for carburized parts and, in some instances, for their response to heat treatment, and since manganese increases the speed of carburizing, insures high casehardness and produces moderate response to quenching, it is to be desired. For low carbon openhearth screw stock, therefore, carbon should be under about 0.20%, manganese between 1 and 1½%, phosphorus low (since manganese is high), the sulphur again depending on quality requirements and rolling conditions.

High carbon openhearth screw stock is really not a free-cutting steel in the strictest sense of the word, since it does not compare in machining qualities with the other two types. It is designed primarily for high strength and response to heat treatment. While sulphur additions help its machining properties, it is nevertheless a relatively poor-machining steel. Carbon is usually in the range of 0.30 to 0.40%, manganese from 1 to 2%, depending on what particular heat treating trick it is expected to perform, and sulphur as high as quality requirements will permit, usually somewhere in the range of 0.10 to 0.15%.

Until the last few years, chemistry was about the only factor considered in determining whether a steel should machine freely, but we know now that there are many other contributing factors. Even the as-rolled grain size produces some effect. It is traditional that screw stocks should be finished hot, and the principal benefit of this is in producing a coarser grain structure, as rolled. This is consistent with our theory of machinability, since coarse-grained material has lower strength and lower ductility than fine-grained, and we would, therefore, expect machinability to be favored by coarse grain size.

The as-rolled grain size is a separate and distinct proposition from the McQuaid-Ehn grain size after carburizing. We do not believe that inherent austenitic grain size and McQuaid-Ehn grain size have any *direct* effect on machinability, since fine-grained (McQuaid-Ehn) steels can have a coarse-grained as-rolled structure if finished on the hot mill at the proper temperature. However, the fine-grained McQuaid-Ehn steels are made with relatively large additions of aluminum and some of this aluminum may be present as aluminum oxide, which is very abrasive, and may materially shorten tool life.



The most important factor in the machinability of free-cutting steels aside from chemistry, however, is the effect of cold working.

The effect of cold working on low carbon steel is the same as the effect of increased carbon, manganese, and phosphorus. That is, cold working increases the strength and decreases the ductility. Also, cold working exhausts some of the inherent ductility and to this extent embrittles the ferrite which, as we pointed out when we were discussing manganese and phosphorus, is a better way of reducing ductility than introducing another structural component or inclusion. The relation of the decrease in ductility to increase in tensile strength is more favorable with cold working than it is with carbon, manganese, or phosphorus. With the normal amount of draft used in cold drawing, the tensile strength is increased about 30%, while the ductility, as measured by the elongation in 2 in. in a tensile test, is reduced about 50 or 60%. According to our theory, therefore, this should be a very favorable method of improving the machinability, and such is found indeed to be the case.

COLD WORK FOR SMOOTH FINISH

Cold working plays another important part in improving machinability, particularly from the standpoint of finish. When steel is hardened by cold working, slip occurs along the cleavage planes in the ferrite so that after cold working we can visualize the ferrite crystals as composed of layers of soft ferrite separated by a strong amorphous film at the slip planes. These amorphous films give support to the soft ferrite layers and make it very easy for the tool to cut cleanly through the successive thin layers of ferrite, leaving a smooth finish on the machined surface. The average thickness of these ferrite blocks can be reduced by additional cold working, and up to a certain point the finish in machining can be so improved.

In this respect there is a similarity of principle involved in the machining of lamellar pearlite. Lamellar pearlite is the most favorable form for carbon to occur in steel for free machining—unless there is too much of it as there is in very high carbon steels. In such cases, the strength is too high for free machining and it is necessary to spheroidize or divorce a part of the carbon to weaken the steel. The carbon that is not spheroidized, however, we want in the lamellar form, for it can readily be imagined

how a cutting tool would snap off the thin plates of cementite and cut cleanly through the thin layers of ferrite that are supported by the plates of cementite. This is the same principle that applies in machining cold-worked ferrite, and it is very useful in obtaining good finish on machined parts, particularly on such operations as broaching and gear cutting.

Another characteristic of cold-worked steel having an important bearing on machinability is the manner in which it stretches prior to rupture. If we take a piece of hot-rolled steel and a piece of the same bar after cold drawing and break them in a tensile machine, after first punch marking the specimen every inch of length for 8 in., we find that the manner of elongation of the two samples prior to rupture has been quite different. If we measure the distance between punch marks on the broken test pieces, we find that the hot-rolled sample shows marked elongation for several inches on either side of the break while practically all of the elongation on the cold-drawn sample occurred close to the fracture.

We might say that the hot-rolled sample shows high general elongation while the cold-drawn sample does not. When the chip is torn loose from cold-drawn steel by the cutting tool, the volume under the chip that is affected is very small while in the case of hot-rolled material the steel is dragged or distorted for some distance below the surface, and this results in a rougher finish on the machined part and greater tool wear.

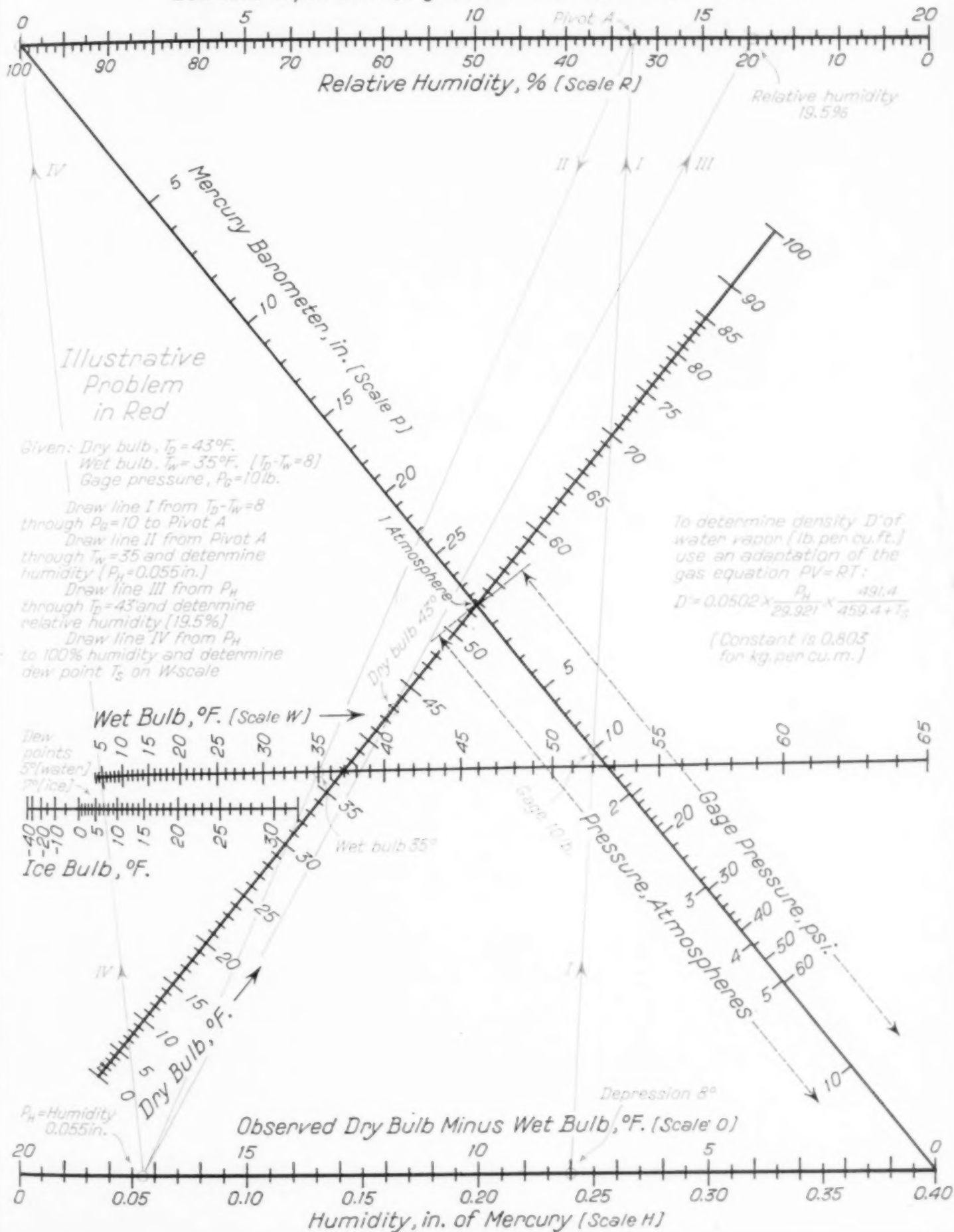
APPRAISAL OF PROGRESS

These, we believe, are some of the more important underlying principles that explain why free-machining steels machine freely. Improvement in machining properties has resulted largely from a better understanding of the principles. The extent of this progress can perhaps most readily be appreciated by comparing the feeds, speeds, and production on some of the automatic screw machines of ten or 15 years ago with similar parts today. The average increase in production would probably be in the neighborhood of 100%. The demand in the future for further improvement in machinability will no doubt be just as insistent as it has been in the past, and if this improvement is to be realized, it will be because of a still better understanding of the underlying principles.

Psychrometric Chart, Low Range

By Donald B. Brooks; National Bureau of Standards. Publication M-146

Sea Level Equivalent, Dry Bulb Minus Wet Bulb, °F. (Scale E)



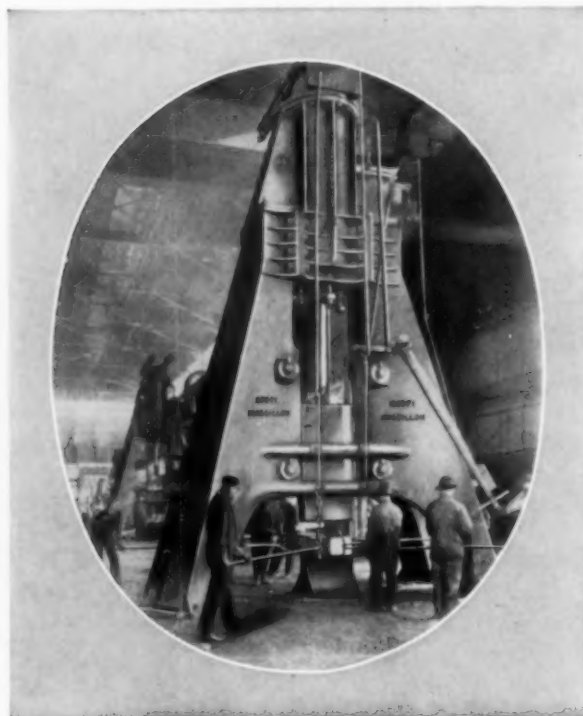
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METAL PROGRESS

PROFITS

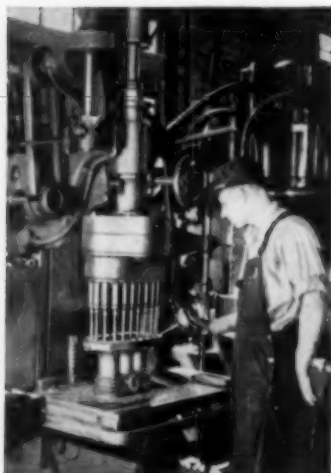
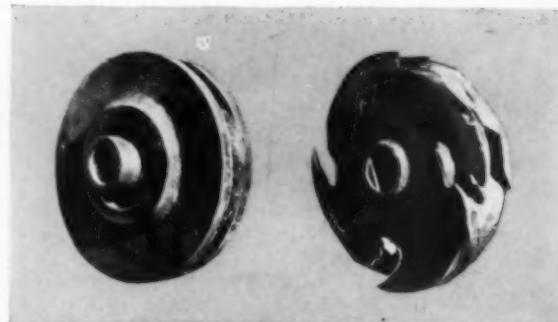
leak through many a loophole

NICKEL CAN EASILY PLUG



MACHINERY repairs and replacements often run higher than you anticipate—often throw you for a *loss* when you are expecting to make a *gain*. Frequently, time lost when machines are out of action, may be far more costly than the expense of making the repairs themselves. But when equipment is fortified at vulnerable points with strong, tough alloys of Nickel, service records often stretch for astonishingly long periods. At left, a forging hammer illustrates the point. Located in a large Ohio Valley plant, it has bushings of Nickel alloy iron, produced by the Continental Roll and Steel Foundry Company. Because of wear in the bore it was recently decided to replace these bushings. When the records were looked up it was found that they had served for *ten* years. Bushings of the same composition had also served another hammer in the same plant for *twelve* years. Hence, when the new order was placed the same producer was asked to duplicate the original composition of Nickel cast iron. A record, demonstrating the need for keeping a record.

BEFORE and after — what happens to plain white cast iron impellers operating in pumps handling highly abrasive material consisting of 73% solid matter. Failure at the end of 551 hours was the average record of eight of these impellers. Yet, operating under identical service conditions, six NI-HARD® Nickel-chromium cast iron impellers demonstrated an average life of 1319 hours, a ratio of 2.39 to 1 in favor of NI-HARD. These results were obtained from records compiled at the Copper Cliff, Ontario, operations of The International Nickel Co., Inc.



UNDER the high-speed multiple drill pictured at the left is a compressor cylinder destined for use in refrigeration apparatus made by the York (Pa.) Ice Machinery Corporation. Among the requirements that must be met by a metal for this service are pressure-tightness, high wear-resistance and ease of machinability. All of these are supplied by Nickel cast iron, hence this is the material used by York for cylinders, top heads, pistons, crankcases and bearing heads. The company states that these parts in which Nickel is used *have never yet required replacing because of wear*. We invite consultation on the use of the alloys of Nickel in your equipment.

* NI-HARD — Reg. U. S. Pat. Off. by The International Nickel Co. — Canadian Patent No. 281,986.

NICKEL CAST IRONS

THE INTERNATIONAL NICKEL COMPANY, INC., NEW YORK, N. Y.

Metal Progress; Page 66

LETTERS FROM

HOME AND ABROAD

CRUCIBLE TOOLSTEEL

SOMETIME during the press run on last month's METAL PROGRESS, the engraving in Mr. Bigge's article on page 773 showing a cross-section of a 16-in., 3600-lb. modern ingot of high speed steel was damaged, so that it appeared to have two or three thumb-print smudges on it—or, even worse, corresponding deep-seated spongy regions! The printer, not being a metallurgist, failed to recognize the incongruity of such a presentation, but this does not excuse his careless press work. A new engraving has been made of the original photograph and is presented herewith, and the pressman had better do a good job of it this time—or else. . . .

THE EDITOR

IDRONAL

A LIGHT ALLOY FOR MARINE USE

TURIN, ITALY

To the Editor of METAL PROGRESS:

European practice in the field of corrosion resisting alloys of aluminum has shown some important changes since the alloys developed several years ago in Germany under the general name "KS-Seewasser" (KSS) were generally adopted, especially for naval applications in all European navies.

As is well known, these alloys contain comparatively low percentages

of magnesium (from 1.8 to 2.2%) and comparatively high percentages of manganese (1.2 to 1.4%), in addition to small quantities of antimony, silicon, iron and titanium. They show excellent physical properties and corrosion resistance, but their casting qualities are not completely satisfactory, so that serious troubles and difficulties may arise when castings of intricate forms are to be manufactured.

In recent years, extensive researches made in different European laboratories and works have led to the conclusion that the best solution of this complex foundry problem is obtained by completely modifying the composition of KSS alloys—namely, by increasing the magnesium content (up to 5% and even 12%) and reducing the manganese content to 0.5% to 0.3%, or even totally eliminating it.

Alloys of these new compositions are now used very extensively, especially in Germany and in Italy, under the name of "Idronal." They show practically the same corrosion resistance as KSS, better physical properties, and quite remarkable casting properties. Different compositions are adopted for various applications. Usually alloys containing less than 5% magnesium do not require any heat treatment; alloys with magnesium in the range between 5 and 12% are generally heat treated.

The results of recent researches,

16-In., 3600-Lb.
Modern Ingot of
High Speed Steel

January, 1938; Page 67

published by R. Guastalla in *Alluminio*, October 1936, while confirming the known high resistance of these alloys, both to simple corrosion and to contact corrosion, have emphasized their excellent physical and casting properties. A great number of test pieces were taken from different parts of large castings of very complicated forms made of KSS and of Idronal. Typical tension, impact, bend, hardness, and other common tests show not only the superiority of Idronal but a much greater uniformity of these properties in the different parts of the castings, when compared with KSS castings made from the same patterns.

In addition to this, the good casting properties of Idronal have the very important effect of completely eliminating all cracks and porosities. Cast cylinders, perfectly watertight under high pressures, can be easily obtained, while similar cast cylinders of KSS require special treatments such as pressing to be rendered watertight.

Among the different compositions, the more frequently used are "Idronal 51" (5% Mg, 1% Si) and "Idronal 7" (7% Mg). The complete analysis of a typical casting of Idronal 51 is Mg 5.20%, Si 1.35%, Fe 0.34%, Cu 0.04%, aluminum balance.

These extensive experiments by Guastalla show that "Idronal 7" gives the best results for naval applications, both for its chemical resistance to the action of sea water, and for its physical properties.

FEDERICO GIOLITTI
Consulting Engineer

FERROMANGANESE FROM LOW GRADE AMERICAN ORE

STOCKHOLM, SWEDEN

To the Editor of METAL PROGRESS:

The importance of developing some industrial process for concentrating manganese from the low grade manganiferous ores which occur in large amounts in the United States, in order to secure a local source of necessary ferromanganese for the steel industry, has been emphasized in this publication and elsewhere on several occasions. Quite recently an editorial appeared in the November issue, under the title "Where Do We Go From Here?" which touched on this important strategic and industrial problem. A short note on the concentration process developed by the author might therefore be of interest.

From an earlier and thorough investigation

by T. L. Joseph and S. P. Kinney on "Minnesota Manganiferous Iron Ore in Relation to the Iron and Steel Industry" (published as Bulletin of the University of Minnesota, No. 12, 1927) it has been found "that an important problem lies in developing a process for the treatment of ores which contain from 8 to 12% manganese and 0.2 to 0.3% phosphorus." Furthermore, it has been pointed out by E. Newton in his work on "Manganiferous Iron Ores of the Cuyuna District" (Bulletin of University of Minnesota, No. 5, 1918) that this preferably should utilize "various ores in their natural condition by means of slightly modified metallurgical practice." The present writer's process is believed to meet these reasonable commercial requirements very well.

By melting in the blast furnace Cuyuna "brown ore" containing, for instance, 40% iron, 10% manganese and 0.3% phosphorus, there may be obtained a spiegeleisen containing 14% manganese and 0.5% phosphorus, an alloy which as such is of no value to the steel industry. However, if this alloy is given a very simple slag treatment by adding certain oxides and sulphides, an easily fusible slag (melting point from 2200 to 2350° F.) is formed in one or two minutes, containing as much as 60% manganese as oxide while its content of iron is only 1 to 2% and that of phosphorus less than 0.05%. The remaining molten metal contains most of the iron, and is a valuable by-product. The manganiferous slag also contains low percentages of SiO_2 and Al_2O_3 , and these are not essential for the process. Subsequent recovery of manganese from this slag is practically 100% in the form of a very high grade ferromanganese, containing at least 80% manganese and less than 0.1% phosphorus.

Experiments made in the laboratory in a small metallurgical furnace and in industry have proved the efficiency of the process. Only ordinary metallurgical furnaces are used. (See H. Bansen, "Die Rohstofflage und Manganfrage in der Roheisenwirtschaft," *Stahl und Eisen*, Vol. 57, p. 1109, 1937.)

The raw material used may contain any amount of iron, manganese, phosphorus, and sulphur. The SiO_2 content of the ore is preferably not too high, on account of the slag volume in the blast furnace. Calculations of costs made for some actual cases indicate the process to be economical.

HELGE LOEFQUIST
Metallurgical Engineer

FLAW POSITION LOCATED WITH GAMMA RAYS

BETHLEHEM, PA.

To the Editor of METAL PROGRESS:

It has been known for some time that a flaw below the surface of a metal object can be determined by taking a second radiograph, or using a double exposure with a measured displacement of the object (or of the radiant source) from its former position. The shadow of the flaw is thus displaced by an amount which is geometrically proportional to the distance x from flaw to film. While there is every reason to expect that the same methods would apply in the case of radiography by gamma rays as in that of X-rays, this point was made certain by a simple experiment directed by Professor Doan of the metallurgical department of Lehigh University.

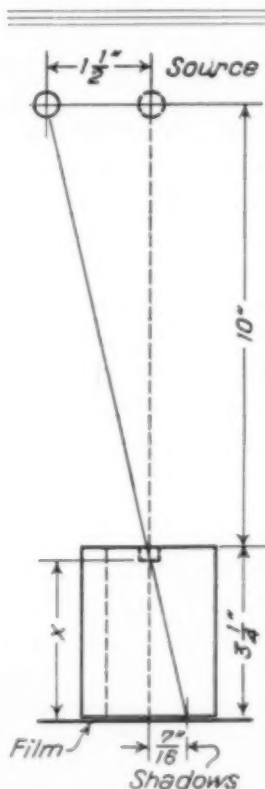
A specimen of mild steel 3 in. thick with a hole of $\frac{1}{8}$ in. diameter and $\frac{1}{4}$ in. depth on the surface was prepared. It was exposed to a 50-millicurie source of gamma rays for 22.5 hr. at $13\frac{1}{4}$ in. distance, source to film, in a position as indicated in the sketch. Then the radiant source was moved $1\frac{1}{2}$ in. from the original position

Two spots were produced on the film, shown below. The distance between them was found to be $\frac{7}{16}$ in. center-to-center. Hence by trigonometry the distance from flaw to film, marked x in the sketch, was calculated to be 3 in.—that is, the flaw lies on the surface, as was known to be the case.

As in X-ray radiography, this method is applicable wherever the flaw is situated in the test object. For example, putting another layer of steel in front of the hole would not change the position of its "shadow," provided no other distances were changed.

S. S. YOUNG
Lehigh University

*Gamma Radiogram (Double Exposure)
of Artificial Flaw in 3-In. Steel Block,
and Sketch Showing How the Position
of Deep-Seated Flaws May Be Located*



REFINING THE STRUCTURE OF CASTINGS

PARIS, FRANCE

To the Editor of METAL PROGRESS:

To obtain the best mechanical strength of cast parts it is important not only to avoid any visible or micrographical physical defects, but also to secure the finest possible solidification structure. Moreover, a fine structure is indispensable to the efficacy of heat treatments such as hardening and tempering, and for this reason these heat treatments have not until recently been used on castings. There is no recourse to hot or cold working to refine the structure in a casting as there is with forged and rolled parts; the only recourse after solidification is to a regenerative heat treatment for alloys which undergo transformation in the solid state, such as steel.

Several processes may be used to refine the solidification structure:

1. Increasing the solidification rate by accelerating the cooling. This can be done in the foundry by diminishing the thickness and by raising the conductivity of the mold. Thus the best mechanical properties, particularly after heat treatment, can be obtained on thin pieces, chill-cast. Aluminum bronze pieces, not forged, after hardening and tempering gave a tensile strength of 100,000 psi. with 10% elongation in 4 in.; after other treatments a tensile strength of 85,000 psi. with 25% elongation was achieved. Chill casting is also used with the hardenable light aluminum alloys.

2. Stirring during solidification so as to increase the number of nuclei and at the same time impede their growth. This process has been used for a long time by the chemical industry to obtain fine crystals. The stirring may be mechanical, magnetic, thermal, acoustic or otherwise. (Ultra sound waves can modify the duration and structure of solidification, as noted by Sokoloff for zinc.) This is one of the advantages of centrifugal casting. Centrifugally cast tubes have a finer structure and this fabrication process is developing remarkably in France and Belgium.

3. Finally, the two quantities characterizing crystallization may be varied — (a) the birth rate, N_c (number of nuclei or centers of crystallization originating in a unit of volume and time), and (b) the rate of growth V_c of the crystals (development of crystals from the nuclei or pre-existing crystals).

These two factors are influenced, often to a considerable extent, by alloying additions in solution. That which decreases V_c (that is, interferes with crystal growth) or increases N_c (that is, multiplies the crystalline nuclei) refines the structure. Thus, the solidification structure of zinc can be refined by cadmium, of some steels by titanium and molybdenum, of ferritic chromium steels by nitrogen, of aluminum and some of its alloys by titanium and cerium, and of the aluminum-silicon alloy (Alpax) by sodium or alkaline fluorides.

Additions which cause a peritectic reaction also refine the structure—for instance, the addition of iron or cobalt to copper. (Iwase, Asato, and Nasu). Likewise, the presence of an electric and magnetic field (obtained by passing direct or inducted current through the ingot) may have some influence on the electromagnetic cohesive forces governing the solidification structure. This has been discussed at some length by Saklatwalla.

A general process to refine the structure consists in introducing new crystalline nuclei during solidification, thus increasing N_c artificially. For this purpose, solid metal in the form of plates, wires, or other forms is introduced into the liquid metal or into the mold. These pieces are of such thickness that they dissolve almost completely at the temperature of solidification. There must be a definite ratio between the dimensions of the solid pieces and those of the part being cast, taking into account the casting temperature, for this process to be effective.

We know that not only isomorphous crystals act in this way, but also that solid particles of an entirely different nature may act as crystallization nuclei. Some inclusions have this effect, and it is this phenomenon which explains the influence on the structure of various reducing or deoxidizing agents, whose products of deoxidation are very fine solid particles and act as so many supplementary crystallization centers, and thus refine the solidification structure in alloys having a tendency to undercooling. On this supposition oxidizing and deoxidizing agents may be added

simultaneously. Thus the solidification structure of gray cast irons has recently been refined by adding simultaneously silico-calcium and sodium carbonate or bichromate (A. Portevin and R. Lemoine, *Comptes Rendues*, vol. 203, page 237, 1936). Strong cast iron with very fine graphite is obtained in this way.

According to some authors (Keil, Mitsche) the precipitation of graphite should be a role only of the iron silicate particles, but these authors give only an indirect proof based upon their assumption that this effect occurs when iron oxide and silica are present simultaneously, and the result cited above does not seem to necessitate such a hypothesis.

In any event, this consideration of artificial nuclei, whether similar to or different from those that appear during solidification, may introduce many valuable methods of refining the solidification structure and consequently the mechanical strength of cast metals and alloys.

The efficacy of this action depends wholly on the tendency toward undercooling of the material under consideration. In high silicon cast irons, which have no tendency toward undercooling, the effect does not occur, and furthermore (according to Norbury and Morgan writing in *Journal of the Iron and Steel Institute*, 1936) the untimely introduction of artificial nuclei might produce a coarser structure.

ALBERT PORTEVIN

Professeur Suppléant

Central College of Arts and Manufacture

SURGEONS WANT AN ALLOY FOR BROKEN BONES

NEW YORK CITY

To the Editor of METAL PROGRESS:

To hold broken bones together, orthopedic surgeons use metal screws, pins, pegs, plates and bands. Such fastenings, however, do not last long because they cause decay in the bones which they are intended to repair. This is invariably due to electrolysis, three San Antonio, Texas, surgeons reported to the December gathering of Southern Medical Association, because of the use of metal combinations having different electromotive forces.

Having realized this, these surgeons—Charles Scott Venable, Walter Goodhoe Stuck and Asa Beach—sought a strong alloy which did not react to the body's salty fluids. The best they found was "vitallium" (cobalt 65%, chromium 30%, molybdenum 5%, manganese, silicon). They think that the following would



Screw of Cobalt-Chromium-Molybdenum Alloy Shows no Signs of Deterioration Eight Months After Fixation in Splintered Bone

be better and ask metallurgists to make it for the use of surgeons: Cobalt 65%, vanadium 30%, molybdenum 5%, manganese, silicon.

In their researches, which required the breaking and mending of legs of 50 dogs, these surgeons discovered that plated metals showed the greatest reaction in body fluids. They were able, they reported in the *Annals of Surgery*, "to demonstrate the transference of metallic ions from one plated screw to the substance of another screw of different metal in compliance with the law of e.m.f. The reason is that, when plating becomes eroded or chipped, the body fluids can come in contact with the two metals side by side and a battery is at once established. This is forcibly illustrated in our experiments with chromium plated steel screws. Proof of electrolytic activity in the tissues is the fact that we have been able to recover chromium from the zinc of a brass screw, copper from the chromium of a chromium plated steel screw, copper from a silver plated steel screw, and zinc from the substance about a galvanized iron screw."

They condemn all chromium plated bone hardware, because when chromium becomes dissolved in the fluids of the body it becomes a serious poison.

And these San Antonio surgeons distrust "stellite, nickel-free rustless steel, high nickel (22%) rustless steel, low nickel (9%) rustless steel . . . because of the presence in all rustless steels of such a high percentage of iron, which is so subject to the action of body fluids and which sets up hysteresis and local electrolytic changes in the alloys."

MYRON WEISS
Associate Editor
Time News magazine

EDITOR'S NOTE — One does not need to be an anti-vivisectionist to pity the poor dogs who were used to prove a metallurgical commonplace. If these surgeons had consulted any textbook on corrosion, they would have found that transfer of metallic ions can be visually demonstrated in gelatine by Walker's ferroxyl test. If they had talked to any electrochemist, they would have been warned of the difficulty of making non-porous electroplates — especially in chromium. Why *plated* hardware, of all things, should ever be used is beyond imagination. In view of the hospital and surgical charges the victim is called upon to pay, why should a few cents or a few dollars be shaved off the repair parts permanently embedded within him?

While "vitallium" is not listed in Woldman and Dornblatt's "Engineering Alloys," it appears to be stellite No. 6 with molybdenum replacing tungsten. Metallurgists probably would consider that this would be a reasonable thing to try, if the bodily fluids contain chlorine ions. Since "hastelloy" (about 58% nickel, 17% molybdenum and 14% chromium) has demonstrated its ability to resist hydrochloric acid in commercial equipment, it would be interesting to know if it would not also be suitable for osseous joinery (if it could be determined in the regular course of hospital operations without further requisitions on the dog pound). Or, why not try Rezistal No. 4 (18-25-3 Cr-Ni-Si) which in the form of dental plates is so resistant to saliva and dilute organics that it has no taste whatever? Such would appear to be a more reasonable program of tests, since it might be doubted whether the 30% vanadium alloy proposed by the surgeons would have special merit. To one who considers plated ware it certainly would not appeal as cheap.

FORGING MACHINE DIES

TIFFIN, OHIO

To the Editor of METAL PROGRESS:

The data sheet entitled "Rules Governing Forging Machine Dies" published in last October's METAL PROGRESS (adapted from Bulletin No. 27 of The National Machinery Co.) contains two misstatements which may lead customers into trouble on cone upsets, many of which are used.

Under note (c), Rule 4, it is stated that

HOW ABOUT "BLINDFOLD TEST for HEAT TREATERS?

Directions:

1. Put in one pot of
PARK - KASE
LIQUID CARBURIZER
2. No additions or formula-
tions—no guesswork—this
can be done blindfolded.

Results:

1. Heat treater knows it's
Park-Kase for there are no
fumes—Park-Kase puts on
its own carbonaceous cover.
2. Heat treater can feel the
cleanliness of material
treated—easily cleaned
from oil or water quench.

CONVINCED THAT IT IS
PARK-KASE—The Heat Treater
removes the blindfold and finds that
in addition—the pot life is longer
... he has a case depth of .015" in
one hour at 1550° F.

He has been using

PARK - KASE
LIQUID CARBURIZER

a laboratory controlled product
manufactured by a company that
has specialized in heat treating
materials for over a quarter of a
century.

PARK CHEMICAL CO.
DETROIT

tapered holes are proportioned as to their diameters at midlength. This is an error. The necessary proportion in the cone must be made at a position which represents one half of the length of unsupported stock measured at the position when upsetting begins. Cones made according to the suggestion in the data sheet would not prove satisfactory.

Under note (d), Rule 2, it is stated that on tubing the wall thickness cannot be increased more than 50% at one blow. This would be correct if the increase in thickness were partially on the inside and partially on the outside of the tubing, or in other words, if it were uniformly divided. However, this seldom if ever occurs because most upsets on tubing are either fully external or fully internal. On *external* upsets, the possible increase in wall thickness at one blow is only 25%. Many customers fail on tubing upsets by overlooking this practical fact.

On *internal* upsets it is possible to do almost unlimited upsetting because the arch effect of the wall prevents internal buckling, and, of course, the die supports the outer wall. In fact, a very desirable practice on the external upsetting of tubing is to first make an internal upset of whatever thickness is desired, and then in the next die impression expand the hole to the original tubing size and lay the stock out into the external die impression.

The rules contained in our Bulletin and your data sheet apply to dies for hot forging. It is not so easy to set forth rules for cold heading, except to state in a general way that about $2\frac{1}{2}d$ represents the limit of unsupported stock, such as referred to in Rule 1.

On cold upsetting the length of stock permissible under Rule 1 seems to vary inversely with the strength of the material. As higher strength material is upset cold, the permissible length of unsupported stock becomes less. If an attempt is made to upset stock cold having the tensile strength of approximately 100,000 psi., it is found that the $2\frac{1}{4}d$, or possibly even $2d$, is the permissible limit.

Cold upsetting, being almost invariably on small diameter work, makes it much more difficult to determine these upsetting laws, but if on Rule 1, $2\frac{1}{2}d$ is used, and on Rule 2, $1.3d$ is followed, it will meet the requirements on all except extremely hard stock.

E. R. Frost
President
The National Machinery Co.



SUB-ZERO DEPENDABILITY



The toughness of steel at low temperatures is a vital factor in the performance of many different types of machines. Just for example, hundreds of motor vehicles must operate every winter at temperatures that make good sub-zero impact strength in highly stressed parts a necessity.

Molybdenum steels, when properly heat-treated, have excellent impact properties at low temperatures. Investigation shows that they retain their toughness remarkably, even at temperatures as low as -90°F .

Consequently, Molybdenum steels offer great possibilities for the manufacturer of equipment that must work either continuously or intermittently at low temperatures. Advantage can be taken of their established price and fabricating economy, with perfect assurance of their performance.

We will be glad to send detailed information on the low-temperature impact properties of several widely used Molybdenum steels to any one interested. Climax Molybdenum Company, 500 Fifth Avenue, New York City.

PRODUCERS OF FERRO-MOLYBDENUM, CALCIUM MOLYBDATE AND MOLYBDENUM TRIOXIDE

CLIMAX MO-LYB-DEN-UM COMPANY

MOLY

January, 1938; Page 73

PERSONALS

R. C. Jordan ⚙, formerly with Wickwire-Spencer Steel Co. in Worcester, Mass., is now manager of sales for Crucible Steel Co. of America, New York.

Appointed sales representative in the New York area for E. F. Houghton & Co.: **Stanley D. Margerum** ⚙.

Conferred upon **Francis C. Frary** ⚙, director of research, Aluminum Research Laboratories of the Aluminum Co. of America: The Pittsburgh Award for 1937, by the Pittsburgh Section of the American Chemical Society.

On a 30-day observation tour of the British West Indies: **Myron Weiss** ⚙, associate editor of *Time* Newsmagazine, who will study the health, medical and scientific activities on the islands.

Frederick J. Elliott ⚙, formerly with E. F. Houghton & Co., has been appointed Cleveland district sales manager for Rustless Iron and Steel Corp. of Baltimore.

Harry J. Kicherer, vice-chairman of the North West Chapter ⚙, has joined the manufacturing staff of the Tractor Works, International Harvester Co., Chicago.

Charles A. Turner, Jr. ⚙, formerly pit foreman in the open-hearth at the Homestead Works of Carnegie-Illinois Steel Corp., is now a research assistant in the research department of the Midvale Co., Philadelphia.

Neil T. Sawdey ⚙ has been made works manager for Globe Stamping Co., Cleveland.

D. C. Dilley ⚙ has left the firm of A. I. Buehler in Chicago to take the position of metallurgist for the Lindsay Wire Weaving Co., Cleveland.

John W. Hamilton ⚙ is now connected with the Frigidaire Division of General Motors in the process and materials division.

Reappointed chairman of the Ferrous Metals Committee of the Industrial Gas Section, American Gas Association: **Robert G. Guthrie**, past president ⚙, and consulting metallurgist for Peoples Gas Light & Coke Co., Chicago.

Ralph D. Hawkins ⚙, Bridgeport Gas Light Co., Bridgeport, Conn., was appointed chairman of the Non-Ferrous Metals Committee of the Industrial Gas Section, American Gas Association, and **S. Procter Rodgers** ⚙, Consolidated Electric Light & Power Co. of Baltimore, was made vice-chairman.

David K. Miller ⚙, formerly sales representative in the Philadelphia office of Crucible Steel Co. of America, is now district representative in charge of the Baltimore office.

H. J. Georgen has been added to the sales staff of Michiana Products Corp., with headquarters in Chicago.



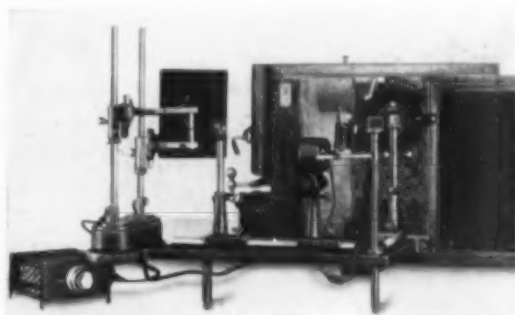
FOR THE ACCURATE SOLUTION OF SPECTRO-ANALYTICAL PROBLEMS



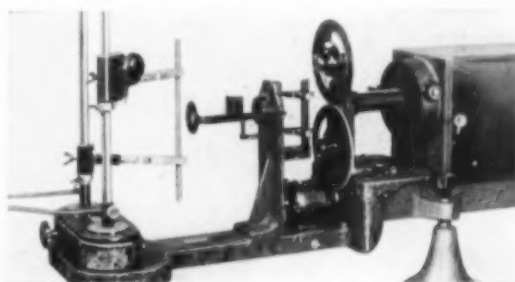
Arc and Spark Stand Illuminating System
Spherical condensing lens, rotary sector disc with motor, cylindrical condensing lens on rigid base.

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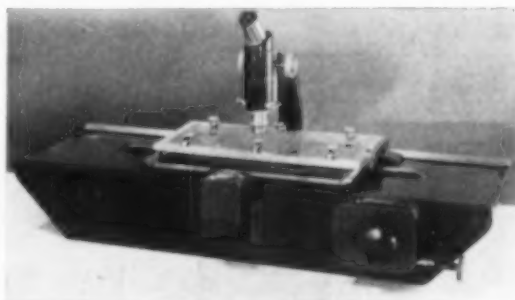
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AUTHORS IN THIS ISSUE

John T. Bryce ⚙, senior author of the article on rapid annealing of malleable, is only 28 years old. As a co-operative student at Antioch College he was employed in the metallurgical laboratories of the National Supply Co. in Toledo and of the Army Air Corps, Wright Field, Dayton. After graduation in 1933 he spent a year and a half as chemist for National Milling Co. and one summer in the foundry of Bunting Brass and Bronze Co. He has held his present position as metallurgist, Surface Combustion Corp., for the past three years.

Junior author **Harry G. Schwab**, born in 1913, is a graduate of University of Toledo. He has likewise been in the employ of Surface Combustion for the past three years, his capacity being that of development engineer.

⚙ ⚙ ⚙
"My claim to some knowledge of enamel," writes **Charles S. Pearce**, who tells about enameled iron in architecture on page 49, "comes from five years' experience as head of the enameling division of the Frigidaire Corp.—the largest wet-process plant in the world, with an annual capacity of better than 20 million sq.ft." Mr. Pearce's recent activity in this field has been as assistant director of personnel for the Farm Security Administration, which is now conducting negotiations to erect 200 steel prefabricated houses at Greenbelt, Md.

⚙ ⚙ ⚙
Seven years after his matriculation in 1920 at Institute of Technology in Braunschweig, Germany, **Hans Osborg** received the degree of doctor of engineering summa cum laude. Two years later he

came to the United States and was in charge of the metal department of Maywood Chemical Works in New Jersey until 1934. Since then he has been engaged in co-operative industrial research and development work. Long interested in the minor metals, Dr. Osborg is somewhat of an authority on lithium (see page 1189 of ⚙ Metals Handbook) and contributes a paper on minor constituents in copper-lead alloys to this issue (page 43).

⚙ ⚙ ⚙
Machinability is a matter of perennial interest to ⚙ members, and none is so well qualified to present an understandable version of our present knowledge on the subject as **J. D. Armour**, metallurgist for 17 years for Union Drawn Steel Co. His preliminary technical training was acquired during four years' study at Carnegie Institute of Technology, two years in France with the 15th Engineers, A.E.F., and a similar period in the Schoenberger Plant and the Aliquippa Works in Pittsburgh.

⚙ ⚙ ⚙
S. L. Case, author of "Damping Capacity and Aging of Steel" on page 54, has been metallurgist with Jones and Laughlin Steel Corp. since 1926. His article is a by-product of a lengthy investigation into the bessemer steel making process. Mr. Case was born and educated in Russia, graduating as chemical engineer from Kiev Polytechnic Institute. Coming to this country in 1915 he was employed as chemist with American Steel and Wire Co., and as Chief Chemist and Metallurgist for American Steel Foundries in Franklin, Pa., prior to his present connection.



John T. Bryce



Hans Osborg



Charles S. Pearce

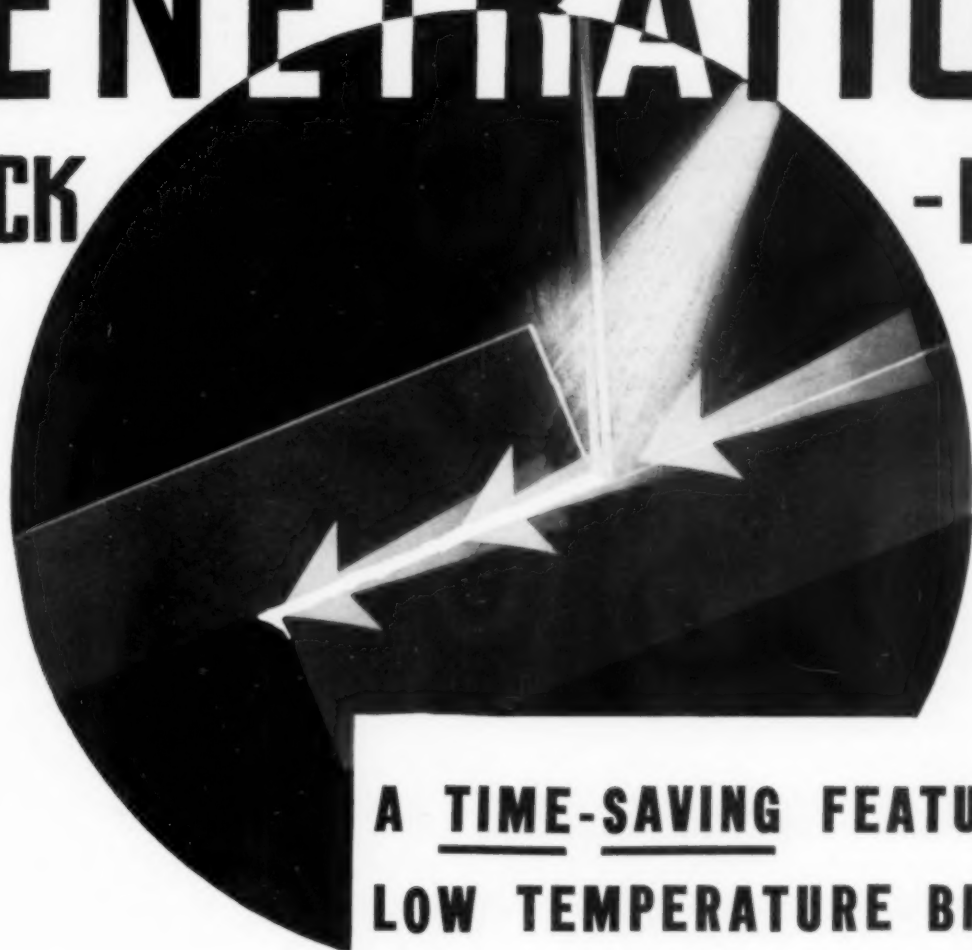


Harry G. Schwab

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(Continued from p. 41) composition to D-steel, except that the test pieces from the rivet bars have an ultimate tensile strength of from 80,000 to 90,000 psi. and an elongation of 20% in eight diameters. Owing to the quenching effect of the surrounding plating, the driven rivets have a tensile strength approaching the upper limit for D-steel.

Main transverse bulkheads, the majority of the deep frames, and the plates and girders under the lower deck were welded. Welded bulkheads were generally constructed of joggled plating, with laps equal to three times the thickness of the plating, with a continuous full weld on the boundary bar side and a continuous light weld on the opposite side. The stiffeners were of flat bar or angle bar, welded to the bulkhead with a continuous light weld on both sides.

An interesting feature of this accident is that it illustrates the behavior of welding under explosive force. Much has been written and said of the strength of welding under various tests, but here is a large structure under the most searching test of all, and it is satisfactory to note that the welding stood up well, particularly on the bulkheads which are of thin mild steel, and where the welding in many places had to withstand severe crumpling. The welding showed itself to be sufficiently flexible to take up distortion which, in a riveted structure, would have caused the rivets to pull through or break. Some failures occurred at laps where the plates were joggled. At such a joint the weld is subjected to both tension and bending when the structure is stressed, and the author would welcome a more extensive adoption of butt joints in welded structures, thus eliminating joggling. In this and other directions it would be well not to carry into welding technique the forms and methods to which we have become accustomed in general riveting practice.

In examining the behavior of the riveted structure, it will be realized that when relatively thin plates are riveted together, failure tends to take place in the plates rather than by shear of the rivets. A marked feature of the damage was the excellent way in which the rivets withstood the shock, and such rivets as were not holding had generally pulled through the plate or shape at their points.

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TEMPERATURE CONTROLLERS

January, 1938; Page 93

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Adolph J. Buehler

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(Cont. from page 48) methods employed for billets, should find application.

Products—To enlarge on the improvements in the mechanical properties of non-ferrous castings would be merely to stress the obvious. As far as the competitive situation is concerned, other factors have an equal importance. Whatever progress has been made in the foundry in recent years, it must be conceded that still greater progress has been made in the various plastic working methods taken collectively, and in methods of joining. Not many years ago engineering design was very largely a question of choosing a casting or a riveted structure. With the rise of the production engineer and the development of a much wider range of fabrication methods, however, designers have been given very much more scope, and a new concept of the utilization of methods and materials has grown up. Therefore the foundry has to meet the onslaught of sheet metal working methods, extrusion—which is producing more complicated sections almost daily, and can now provide closed sections in aluminum alloys—cold upsetting, and welded or soldered assemblies. It is not merely a question of one or other of these methods capturing certain types of engineering components from the foundry, but of ingenious combinations of two or more methods being devised by the production engineer to increase output and reduce costs.

One very important factor in this drift is the untrammelled outlook of those responsible for the newer metal working methods. It is partly because of tradition that orders are often lost to the foundry—particularly the brass or bronze foundry—which might have been secured by a greater exercise of initiative from within.

Outlook—Increasing precision and control of metal, sand, and temperatures are well in evidence, with careful planning taking the place of empirical and individualistic methods. To produce still sounder, stronger, and more uniform castings the foundrymen will require much new information on melting practice and on the properties of alloys prepared under ideal conditions, and a fresh outlook on quite a few points, particularly on pouring methods and on the purification of melts by fluxes and other methods. They will need to pay greater attention to casting under pressure, both for low and high melting point alloys. They can apparently look forward to the development of two new or improved types of technologists—the foundry engineer-cum-metallurgist on one side, and the metallurgical or materials engineer on the other. The future lies to a great extent in the hands of these two working closely together.